

~~NO-A188~~ 152

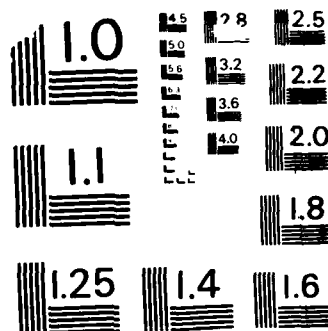
FIELD VERIFICATION PROGRAM (AQUATIC DISPOSAL) EFFECTS
OF BLACK ROCK HARBO. (U) ARMY ENGINEER WATERWAYS
EXPERIMENT STATION VICKSBURG MS ENVIR.
P P YEVICH ET AL. SEP 87 WES/TR/D-87-8 F/G 8/1

1/2

UNCLASSIFIED

F/G 8/1

NL



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

DTIC FILE COPY

121



US Environmental
Protection
Agency

AD-A188 152

FIELD VERIFICATION PROGRAM
(AQUATIC DISPOSAL)

TECHNICAL REPORT D-87-8

EFFECTS OF BLACK ROCK HARBOR DREDGED
MATERIAL ON THE HISTOPATHOLOGY OF
THE BLUE MUSSEL *MYTILUS EDULIS* AND
POLYCHAETE WORM *NEPHTYS INCISA* AFTER
LABORATORY AND FIELD EXPOSURES

by

Paul P. Yevich, Carolyn Yevich, Gerald Pesch

Environmental Research Laboratory
US Environmental Protection Agency
Narragansett, Rhode Island 02882

and

William Nelson

Science Applications International Corporation
Narragansett, Rhode Island 02882



US Army Corps
of Engineers

Destroy this report when no longer required. Do not return it to the originator.

The findings in this report are not to be construed as an official Department of the Army position unless so designated by other authorized documents.

The contents of this report are not to be used for advertising, publication, or promotion purposes.
Citation of trade names does not constitute an official endorsement or approval of the quality or suitability thereof for products.

This document is the property of the Army Research Office-Durham. It is to be used only for the purposes specified in the report. It is not to be distributed outside the Army Research Office-Durham. It is not to be used for advertising, publication, or promotion purposes. It is not to be used for official endorsement or approval of the quality or suitability thereof for products.

SUBJECT: Transmittal of Field Verification Program Technical Report Entitled "Effects of Black Rock Harbor Dredged Material on the Histopathology of the Blue Mussel *Mytilus Edulis* and Polychaete Worm *Nephtys Incisa* After Laboratory and Field Exposures"

TO: All Report Recipients

1. This is one in a series of scientific reports documenting the findings of studies conducted under the Interagency Field Verification of Testing and Predictive Methodologies for Dredged Material Disposal Alternatives (referred to as the Field Verification Program or FVP). This program is a comprehensive evaluation of environmental effects of dredged material disposal under conditions of upland and aquatic disposal and wetland creation.
2. The FVP originated out of the mutual need of both the Corps of Engineers (Corps) and the Environmental Protection Agency (EPA) to continually improve the technical basis for carrying out their shared regulatory missions. The program is an expansion of studies proposed by EPA to the US Army Engineer Division, New England (NED), in support of its regulatory and dredging missions related to dredged material disposal into Long Island Sound. Discussions among the Corps' Waterways Experiment Station (WES), NED, and the EPA Environmental Research Laboratory (ERLN) in Narragansett, RI, made it clear that a dredging project at Black Rock Harbor in Bridgeport, CT, presented a unique opportunity for simultaneous evaluation of aquatic disposal, upland disposal, and wetland creation using the same dredged material. Evaluations were to be based on technology existing within the two agencies or developed during the six-year life of the program.
3. The program is generic in nature and will provide techniques and interpretive approaches applicable to evaluation of many dredging and disposal operations. Consequently, while the studies will provide detailed site-specific information on disposal of material dredged from Black Rock Harbor, they will also have great national significance for the Corps and EPA.
4. The FVP is designed to meet both Agencies' needs to document the effects of disposal under various conditions, provide verification of the predictive accuracy of evaluative techniques now in use, and provide a basis for determining the degree to which biological response is correlated with bioaccumulation of key contaminants in the species under study. The latter is an important aid in interpreting potential biological consequences of bioaccumulation. The program also meets EPA mission needs by providing an opportunity to document the application of the generic predictive hazard-assessment research strategy applicable to all wastes disposed in the aquatic environment. Therefore, the ERLN initiated exposure-assessment studies at the aquatic disposal site. The Corps-sponsored studies on environmental consequences of aquatic disposal will provide the effects assessment necessary to complement the EPA-sponsored exposure assessment, thereby allowing ERLN to develop and apply a hazard-assessment strategy. While not part of the Corps-funded FVP, the EPA exposure-assessment studies will complement the Corps' work, and together the Corps and the EPA studies will satisfy the needs of both agencies.



A-1

SUBJECT: Transmittal of Field Verification Program Technical Report Entitled "Effects of Black Rock Harbor Dredged Material on the Histopathology of the Blue Mussel *Mytilus Edulis* and Polychaete Worm *Nephtys Incisa* After Laboratory and Field Exposures"

5. In recognition of the potential national significance, the Office, Chief of Engineers, approved and funded the studies in January 1982. The work is managed through the Environmental Laboratory's Environmental Effects of Dredging Programs at WES. Studies of the effects of upland disposal and wetland creation were conducted by WES, and studies of aquatic disposal were carried out by the ERLN, applying techniques worked out at the laboratory for evaluating sublethal effects of contaminants on aquatic organisms. These studies were funded by the Corps while salary, support facilities, etc., were provided by EPA. The EPA funding to support the exposure-assessment studies followed in 1983; the exposure-assessment studies are managed and conducted by ERLN.

6. The Corps and EPA are pleased at the opportunity to conduct cooperative research and believe that the value in practical implementation and improvement of environmental regulations of dredged material disposal will be considerable. The studies conducted under this program are scientific in nature and are published in the scientific literature as appropriate and in a series of Corps technical reports. The EPA will publish findings of the exposure-assessment studies in the scientific literature and in EPA report series. The FVP will provide the scientific basis upon which regulatory recommendations will be made and upon which changes in regulatory implementation, and perhaps regulations themselves, will be based. However, the documents produced by the program do not in themselves constitute regulatory guidance from either agency. Regulatory guidance will be provided under separate authority after appropriate technical and administrative assessment of the overall findings of the entire program.



James Choromokos, Jr., Ph.D., P.E.
Director, Research and Development
U. S. Army Corps of Engineers



Bernard D. Goldstein, M.D.
Assistant Administrator for
Research and Development
U. S. Environmental Protection
Agency

Unclassified
SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE				
1a. REPORT SECURITY CLASSIFICATION Unclassified		1b. RESTRICTIVE MARKINGS		
2a. SECURITY CLASSIFICATION AUTHORITY		3. DISTRIBUTION/AVAILABILITY OF REPORT Approved for public release; distribution unlimited.		
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE				
4. PERFORMING ORGANIZATION REPORT NUMBER(S)		5. MONITORING ORGANIZATION REPORT NUMBER(S) Technical Report D-87-8		
6a. NAME OF PERFORMING ORGANIZATION Environmental Research Laboratory (See reverse)		6b. OFFICE SYMBOL (If applicable)		7a. NAME OF MONITORING ORGANIZATION USAEWES Environmental Laboratory
6c. ADDRESS (City, State, and ZIP Code) Narragansett, RI 02882		7b. ADDRESS (City, State, and ZIP Code) PO Box 631 Vicksburg, MS 39180-0631		
8a. NAME OF FUNDING/SPONSORING ORGANIZATION US Army Corps of Engineers		8b. OFFICE SYMBOL (If applicable)		9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER
8c. ADDRESS (City, State, and ZIP Code) Washington, DC 20314-1000		10. SOURCE OF FUNDING NUMBERS		
		PROGRAM ELEMENT NO.	PROJECT NO.	TASK NO. WORK UNIT ACCESSION NO.
11. TITLE (Include Security Classification) Effects of Black Rock Harbor Dredged Material on the Histopathology of the Blue Mussel <i>Mytilus edulis</i> and Polychaete Worm <i>Nephtys incisa</i> After Laboratory and Field Exposures				
12. PERSONAL AUTHOR(S) Yevich, Paul P.; Yevich, Carolyn; Pesch, Gerald; Nelson, William				
13a. TYPE OF REPORT Final report	13b. TIME COVERED FROM TO	14. DATE OF REPORT (Year, Month, Day) September 1987		15. PAGE COUNT 157
16. SUPPLEMENTARY NOTATION Available from National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161.				
17. COSATI CODES			18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number) Benthos (LC) Dredged Material (WES) Dredging--Connecticut--Black Rock Harbor (LC) (Continued)	
FIELD	GROUP	SUB-GROUP		
19. ABSTRACT (Continue on reverse if necessary and identify by block number) A study was conducted to field verify histopathological changes in two aquatic species, <i>Mytilus edulis</i> and <i>Nephtys incisa</i> , by comparing histological changes under both laboratory and field exposures to contaminated dredged material. A second objective of the study was to determine the degree of correlation between tissue residues resulting from bioaccumulation of dredged material contaminants with histopathological changes. A laboratory dosing system was designed to deliver a constant exposure concentration of suspended sediment (both reference and contaminated dredged material from Black Rock Harbor (BRH)) to the blue mussel <i>Mytilus edulis</i> and the polychaete worm <i>Nephtys incisa</i> . Residue concentrations in both mussels and worms, particularly stable compounds such as polychlorinated biphenyls (PCBs), were found to be closely related to exposure concentrations. Histopathological changes included the female reproductive tract, gills, and gastrointestinal tract for <i>M. edulis</i> and the parapodial epidermis for <i>N. incisa</i> . Histopathological changes (Continued)				
20. DISTRIBUTION/AVAILABILITY OF ABSTRACT <input checked="" type="checkbox"/> UNCLASSIFIED/UNLIMITED <input type="checkbox"/> SAME AS RPT <input type="checkbox"/> DTIC USERS			21. ABSTRACT SECURITY CLASSIFICATION Unclassified	
22a. NAME OF RESPONSIBLE INDIVIDUAL			22b. TELEPHONE (Include Area Code)	22c. OFFICE SYMBOL

6a. NAME OF PERFORMING ORGANIZATION (Continued).

and Science Applications International Corporation

18. SUBJECT TERMS (Continued).

Dredging--environmental aspects (LC)
Histopathology (LC)
Marine Pollution (LC)
Molluscs (LC)
Polychaeta (LC)

19. ABSTRACT (Continued).

observed for specimens of both species following laboratory exposures were directly related to BRH exposure and subsequent tissue concentrations.

There was a definite relationship between histopathological change and tissue residues in *M. edulis* in the laboratory for those BRH contaminants that were bioaccumulated. A residue-effect relationship was not evident for *N. incisa* in the laboratory, since a change in the parapodial epidermis was not considered to be a pathological condition and was the only response reported.

Field exposure estimates of BRH suspended sediments at 1 m above the sediment-water interface indicated that maximum concentrations occurred during the disposal operation, after which exposure concentrations and tissue concentrations of BRH contaminants decreased to background within 1 to 2 months. The general lack of exposure to BRH sediments in the field resulted in no observed histopathological changes in *M. edulis*; consequently, no residue-effects relationships could be determined.

The laboratory-field comparison for *M. edulis* is based upon a comparison of exposure conditions estimated from tissue residues and chemical data. Cluster analysis of the *M. edulis* residue data indicates that field residues are most similar to laboratory exposures to reference material. Field residues during disposal, though elevated, are less than those reported for the lowest laboratory exposure (1.5 mg/l) to BRH sediment. The lack of histopathological responses in *M. edulis* exposed in the field is not unexpected, since field exposures reflect laboratory reference exposures that did not result in histological effects. There is, therefore, excellent agreement between the histopathological data from the lab and from the field.

Laboratory results for *N. incisa* show significant increases in tissue residue values. The only histopathological observation was a darkening and thickening of the epidermal tissue of the parapodia. Field results failed to detect similar changes from *N. incisa* exposed on and around the disposal site. Laboratory and field exposures were analogous as estimated by tissue residues and physical models. Cluster analysis of the *N. incisa* tissue residue data from the laboratory and field revealed no consistency of association; that is, there were no differences. Thus, exposures to *N. incisa* between the laboratory and field were analogous, as was the absence of histopathological changes. The only exception was the thickening and darkening of the parapodial epidermis observed from the laboratory studies. Because of the general lack of histopathological change, residue-effect relationships were not determined.

PREFACE

This report describes work performed by the US Environmental Protection Agency (USEPA), Environmental Research Laboratory, Narragansett, R. I. (ERLN), as part of the Interagency Field Verification of Testing and Predictive Methodologies for Dredged Material Disposal Alternatives Program (Field Verification Program (FVP)). The FVP is sponsored by the office, Chief of Engineers (OCE), US Army, and is assigned to the US Army Engineer Waterways Experiment Station (WES), Vicksburg, Miss. The objective of this interagency program is to field verify existing predictive techniques for evaluating the environmental consequences of dredged material disposal under aquatic, intertidal, and upland conditions. The aquatic portion of the FVP was conducted by ERLN, with the wetland and upland portion conducted by WES.

The principal investigators for this aquatic study and authors of this report were Mr. Paul P. Yevich and Ms. Carolyn Yevich, ERLN; Mr. William Nelson, Science Applications International Corporation (SAIC); and Dr. Gerald Pesch, ERLN. This report was prepared by Dr. D. Michael Johns, Tetra-Tech. Technical support for the histological measurements was provided by Dr. Ester C. Peters, Mr. Michael Casey, and Ms. Suzan Regan. Diving support for the field portion of the study was provided by Messrs. Bruce Reynolds and Norman Rubenstein, ERLN, and Mr. Greg Tracey, SAIC.

Analytical chemistry support was provided by Dr. Gerald Hoffman and Messrs. Richard Lapan, Curtis Norwood, and Frank Osterman, ERLN; Messrs. Richard McKinney, Warren Boothman, Lawrence LeBlanc, and Robert Bowen and Msses. Adria Elskus, Eileen McFadden, and Sharon Pavignano, SAIC; and Ms. Kathleen Schweitzer, University of Rhode Island.

Msses. Joan E. Seites, Barbara S. Gardiner, and Colette J. Brown, Computer Sciences Corporation (CSC), provided word processing support in the preparation of this report. Predictive models of field exposures were supplied by Dr. John F. Paul, ERLN, and Dr. Wayne R. Munns, SAIC. Critical reviews of this report were completed by Drs. John H. Gentile and Gerald G. Pesch, ERLN. Technical reviews by WES personnel were also provided.

The USEPA Technical Director for the FVP was Dr. John H. Gentile, and the Technical Coordinators were Dr. Gerald Pesch and Mr. Walter Galloway.

The study was conducted under the direct WES management of Drs. Thomas M. Dillon and Richard Peddicord and under the general management

of Dr. C. Richard Lee, Chief, Contaminant Mobility and Criteria Group; Mr. Donald L. Robey, Chief, Ecosystem Research and Simulation Division; and Dr. John Harrison, Chief, Environmental Laboratory. The FVP Coordinator was Mr. Robert L. Lazor, and the EEDP Managers were Mr. Charles C. Calhoun, Jr., and Dr. Robert M. Engler. This report was edited by Ms. Lee T. Byrne, Information Products Division, Information Technology Laboratory, WES.

COL Allen F. Grum, USA, was the previous Director of WES. COL Dwayne G. Lee, CE, is the present Commander and Director. Dr. Robert W. Whalin is Technical Director.

This report should be cited as follows:

Yevich, P. P., et al. 1987. "Effects of Black Rock Harbor Dredged Material on the Histopathology of the Blue Mussel *Mytilus edulis* and Polychaete Worm *Nephtys incisa* After Laboratory and Field Exposures," Technical Report D-87-8, prepared by the US Environmental Protection Agency, Narragansett, R. I., for the US Army Engineer Waterways Experiment Station, Vicksburg, Miss.

CONTENTS

	<u>Page</u>
PREFACE.....	1
LIST OF TABLES.....	4
LIST OF FIGURES.....	5
PART I: INTRODUCTION.....	7
Background.....	7
Project Description.....	9
Project Scope.....	11
Laboratory-Field Comparisons.....	12
Residue-Effect Relationships.....	12
Histopathology.....	13
PART II: MATERIALS AND METHODS.....	16
Laboratory Methods.....	16
Field Methods.....	27
Chemical Methods.....	32
Statistical Analysis.....	36
PART III: RESULTS.....	38
Laboratory.....	38
Field.....	66
PART IV: DISCUSSION.....	96
Laboratory Studies.....	96
Field Studies.....	96
Laboratory-Field Comparisons.....	97
Residue-Effect Relationships.....	100
PART V: CONCLUSIONS.....	102
REFERENCES.....	104
APPENDIX A: CHEMICAL FORMULAS, FIELD MUSSEL RESIDUE, AND WORM RESIDUE CONCENTRATIONS.....	A1
APPENDIX B: BLACK ROCK HARBOR (BRH) SEDIMENT PERCENTAGE CALCULATIONS AND SURFICIAL CHEMISTRY DATA.....	B1
APPENDIX C: COMPARISON OF SELECTED CONTAMINANTS IN REF AND BRH SEDIMENTS.....	C1

LIST OF TABLES

No.		Page
1	Collection Information for the Mussels Used in the Laboratory Experiments.....	16
2	Collection Information for the <i>N. incisa</i> Used in the Laboratory Experiments.....	17
3	General Procedures for Processing Tissues.....	25
4	Cruise Number, Deployment Rate, Retrieval Date, and Length of Deployment for Mussels Transplanted to CLIS.....	28
5	Suspended Sediment Concentrations in the Mussel Exposure System.....	38
6	Chemical Monitoring of the <i>M. edulis</i> Exposure System in Experiment 2.....	40
7	Measured Suspended Particulate Concentration (Dry Weight) and Exposure Conditions for Laboratory Tests with <i>N. incisa</i>	41
8	Chemical Analysis of Seawater in Exposure Chambers of 42-Day Experiment Exposing <i>N. incisa</i> to BRH Sediment.....	42
9	PCB Tissue Residues (ng/g dry weight) in Mussels from Laboratory Experiment 1.....	42
10	PCB Tissue Residues (ng/g dry weight) in Mussels from Laboratory Experiment 2.....	43
11	PCB Concentrations (ng/g lipid) in Mussels from Both Laboratory Experiments.....	44
12	Histopathological Findings for <i>M. edulis</i> Exposed to Suspended Particles of BRH Material for 14 Days in the Laboratory.....	59
13	Histopathological Findings for <i>M. edulis</i> Exposed to Suspended Particles of BRH Material for 28 Days in the Laboratory.....	60
14	Histopathological Findings for <i>N. incisa</i> Exposed to Suspended Particles of BRH Material for 28 Days in the Laboratory.....	64
15	Histopathological Findings for <i>N. incisa</i> Exposed to Suspended Particles of BRH Material for 42 Days in the Laboratory.....	65
16	Predicted Range of BRH Suspended Sediment Exposures (mg/l) Required to Achieve the Measured Tissue Residue Values of Mussels Deployed in CLIS.....	67
17	Predicted BRH Suspended Sediment Exposure (mg/l) Based on PCB and Copper Whole Water Chemistry Data.....	69
18	Estimated Concentrations of BRH Sediment (mg/l) Suspended at Sediment-Water Interface Based on PCB Concentrations in Field-Collected <i>N. incisa</i>	71
19	Percent BRH Sediment in the Surficial Sediments at the FVP Disposal Site.....	74
20	Concentration of BRH (mg/l) at the Sediment-Water Interface for Total Suspended Sediment Concentrations of 10 mg/l and 30 mg/l and an Enrichment of 10x.....	74
21	Histopathological Findings for <i>M. edulis</i> Deployed at the BRH Disposal Site.....	90
22	Histopathological Findings for <i>N. incisa</i> Collected at the BRH Disposal Site.....	93

LIST OF FIGURES

No.		Page
1	Central Long Island Sound disposal site and Black Rock Harbor (BRH) dredge site.....	9
2	FVP sampling stations.....	10
3	Suspended sediment dosing system.....	18
4	Suspended sediment oxidation system.....	19
5	Laboratory exposure system for <i>M. edulis</i>	20
6	Proportional diluter used to deliver suspended sediment to the <i>N. incisa</i> exposure chambers.....	23
7	<i>Nephtys incisa</i> exposure chamber.....	24
8	Concentrations of PCB as A1254 in the tissue of <i>M. edulis</i> exposed to BRH suspended sediments for 28 days.....	43
9	Concentrations of PCB as A1254, normalized for lipids, in the tissue of <i>M. edulis</i> exposed to BRH sediment for 14 days.....	45
10	Concentrations of phenanthrene and 178 alkyl homologs in the tissue of <i>M. edulis</i> exposed to BRH suspended sediments for 28 days.....	46
11	Concentrations of fluoranthene and benzo(a)pyrene in the tissue of <i>M. edulis</i> exposed to BRH suspended sediments for 28 days.....	47
12	Concentrations of the SUM of PAHs and CENT of PAHs in the tissue of <i>M. edulis</i> exposed to BRH suspended sediments for 28 days.....	48
13	Concentrations of ethylan and PCB as A1254 in the tissue of <i>M. edulis</i> exposed to BRH suspended sediments for 28 days.....	49
14	Concentrations of cadmium and copper in the tissue of <i>M. edulis</i> exposed to BRH suspended sediments for 28 days.....	50
15	Concentrations of chromium and iron in the tissue of <i>M. edulis</i> exposed to BRH suspended sediments for 28 days.....	51
16	Concentrations of phenanthrene and 178 alkyl homologs in the tissue of <i>N. incisa</i> exposed to BRH suspended sediments for 42 days.....	53
17	Concentrations of fluoranthene and benzo(a)pyrene in the tissue of <i>N. incisa</i> exposed to BRH suspended sediments for 42 days.....	54
18	Concentrations of the SUM of PAHs and CENT of PAHs in the tissue of <i>N. incisa</i> exposed to BRH suspended sediments for 42 days.....	55
19	Concentrations of ethylan and PCB as A1254 in the tissue of <i>N. incisa</i> exposed to BRH suspended sediments for 42 days.....	56
20	Concentrations of cadmium and copper in the tissue of <i>N. incisa</i> exposed to BRH suspended sediments for 42 days.....	57
21	Concentrations of chromium and iron in the tissue of <i>N. incisa</i> exposed to BRH suspended sediments for 42 days.....	58
22	<i>Mytilus edulis</i> , gills from animal exposed to 0-percent BRH. Arrow points to the ciliated column epithelium of the gill filaments.....	61
23	<i>Mytilus edulis</i> , gills from animal exposed to 100-percent BRH. Arrows point to loss of cilia of the column epithelium. Arrow A points to a fusion of the gill epithelium.....	62

<u>No.</u>		<u>Page</u>
24	<i>Nephtys incisa</i> , epidermis from animal exposed to 100-percent BRH sediment. Note thickening and darkening of epidermis and accumulation of particles.....	64
25	<i>Nephtys incisa</i> , epidermis from animal exposed to 0-percent BRH sediment.....	65
26	Suspended sediment concentrations from 1 m above the bottom to the sediment-water interface for storm and background conditions.....	73
27	Concentrations of phenanthrene and the 178 alkyl homologs in the tissues of <i>M. edulis</i> exposed at the specified FVP stations and sampling dates.....	76
28	Concentrations of fluoranthene and benzo(a)pyrene in the tissues of <i>M. edulis</i> exposed at the specified FVP stations and sampling dates.....	77
29	Concentrations of the SUM of the PAHs and CENT in the tissues of <i>M. edulis</i> exposed at the specified FVP stations and sampling dates.....	78
30	Concentrations of PCBs as A1254 and ethylan in the tissues of <i>M. edulis</i> exposed at the specified FVP stations and sampling dates.....	79
31	Concentrations of cadmium and copper in the tissues of <i>M. edulis</i> exposed at the specified FVP stations and sampling dates.....	80
32	Concentrations of chromium and iron in the tissues of <i>M. edulis</i> exposed at the specified FVP stations and sampling dates.....	81
33	Concentrations of phenanthrene and the 178 alkyl homologs in the tissues of <i>N. incisa</i> collected at the specified FVP stations and sampling dates.....	83
34	Concentrations of fluoranthene and benzo(a)pyrene in the tissues of <i>N. incisa</i> collected at the specified FVP stations and sampling dates.....	84
35	Concentrations of the SUM of the PAHs and CENT in the tissues of <i>N. incisa</i> collected at the specified FVP stations and sampling dates.....	85
36	Concentrations of PCBs as A1254 and ethylan in the tissues of <i>N. incisa</i> collected at the specified FVP stations and sampling dates.....	86
37	Concentrations of cadmium and copper in the tissues of <i>N. incisa</i> collected at the specified FVP stations and sampling dates.....	87
38	Concentrations of chromium and iron in the tissues of <i>N. incisa</i> collected at the specified FVP stations and sampling dates.....	88
39	<i>Mytilus edulis</i> , portion of reproductive tract from animal collected at 400E on T + 2. Photomicrograph shows normal ova, cytoplasm, and vitelline membrane.....	92
40	<i>Mytilus edulis</i> , gills from animal collected at 400E at T + 2. Photomicrograph shows normal gill structure for <i>M. edulis</i>	92
41	<i>Nephtys incisa</i> , epidermis from animals collected at 400E at T + 16. Arrow points to epithelium that is a single cell thick and composed of simple squamous to cuboidal cells.....	95
42	<i>Nephtys incisa</i> , developing ova from animal collected at 400E on T + 16. Arrow points to nucleus of oocyte.....	95
43	The relationship between PCB tissue residues and histopathological effects in laboratory exposed <i>M. edulis</i>	101

EFFECTS OF BLACK ROCK HARBOR DREDGED MATERIAL ON THE
HISTOPATHOLOGY OF THE BLUE MUSSEL *MYTILUS EDULIS*
AND POLYCHAETE WORM *NEPHTYS INCISA* AFTER
LABORATORY AND FIELD EXPOSURES

PART I: INTRODUCTION

Background

1. The Marine Protection, Research, and Sanctuaries Act (Public Law 92-532) was passed by Congress in 1972. This law states that it is the policy of the United States to regulate disposal of all types of materials into ocean waters and to prevent or strictly limit disposal of any material that would adversely affect human health, welfare, the marine environment, or ecological systems. The implementation of this law, through the issuance of permits as defined in the final regulations and criteria, is shared jointly by the US Environmental Protection Agency (USEPA) and the US Army Corps of Engineers (CE).

2. In 1977, the CE and the USEPA prepared technical guidance for the implementation of the final ocean dumping regulations in the form of a manual entitled "Ecological Evaluation of Proposed Discharge of Dredged Material into Ocean Waters" (USEPA/CE 1977). This manual specified which test procedures were to be followed in collecting information to be used in making a disposal decision. Among the procedures were those for: (a) chemically characterizing the proposed dredged material; (b) determining the acute toxicity of liquid, suspended particulate, and solid phases; (c) estimating the potential contaminant bioaccumulation; and (d) describing the initial mixing during disposal. These methods have been used for determining the suitability of dredged material for open-water disposal. The procedures in this manual represented the technical state of the art at that time and were never intended to be inflexible methodologies. The recommended test methods were chosen to provide technical information that was consistent with the criteria specified in the regulations. However, use of the manual in the permit process has identified conceptual and technical limitations with the recommended test methods (Gentile and Scott 1986).

3. To meet this critical need, the Interagency Field Verification of

Testing and Predictive Methodologies for Dredged Material Disposal Alternatives Program or the Field Verification Program (FVP) was authorized in 1982. This 6-year program is sponsored by the Office, Chief of Engineers (OCE), US Army, and is assigned to the US Army Engineer Waterways Experiment Station (WES), Vicksburg, Miss. The objective of this interagency program is to field verify existing test methodologies for predicting the environmental consequences of dredged material disposal under aquatic, wetland, and upland conditions. The aquatic portion of the FVP was conducted by the USEPA Environmental Research Laboratory, Narragansett, R. I. (ERLN). The wetland and upland portions, being conducted by WES, are reported in separate documentation.

4. The ERLN was responsible for conducting research on the aquatic option for disposal of dredged material. There were three research objectives for this portion of the program. The first was to demonstrate the applicability of existing test methods for detecting and measuring the effects of dredged material and to determine the degree of variability and reproducibility inherent in the testing procedure. This phase of the program (laboratory documentation) is complete, and the results have been published in a series of technical reports. This information provides insight into how the various methods function, their sources of variability, their respective and relative sensitivities to the specific dredged material being tested, and the degree of confidence that can be placed on the data derived from the application of the methods.

5. The second objective was to field verify the laboratory responses by measuring the same response under both laboratory and field exposures. A basic and often implicit assumption is that results derived from laboratory test methods are directly applicable in the field. While this assumption is intuitive, there are no supporting data from studies on complex wastes in the marine environment. The study reported herein offers a unique opportunity to test this basic assumption.

6. The third objective was to determine the degree of correlation of tissue residues resulting from bioaccumulation of dredged material contaminants with biological responses from laboratory and field exposure to dredged material. However, this study was not designed to address cause-effect relationships, and the multicontaminant nature of the dredged material precludes any such assumptions.

Project Description

7. The aquatic disposal portion of the FVP was a site- and waste-specific case study that applied the concepts and principles of risk assessment. The disposal site for the FVP is a historical site known as the Central Long Island Sound (CLIS) disposal site (1.8 by 3.7 km) located approximately 15 km southeast of New Haven, Conn. (Figure 1). The sedimentology at the

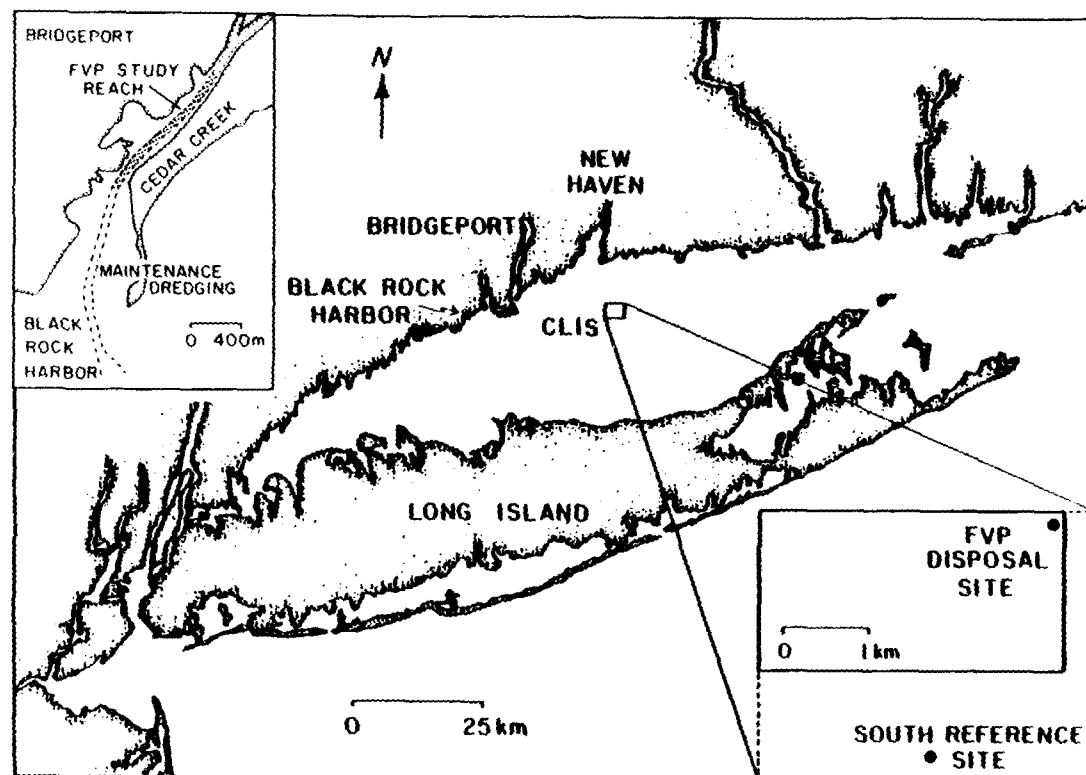


Figure 1. Central Long Island Sound disposal site and Black Rock Harbor (BRH) dredge site

disposal and reference sites is primarily silt-clay, with a mean grain size of 0.013 mm. Thermal stratification occurs from April to September, and during this period bottom salinity is slightly higher than that of the surface. Tidal currents typically dominate the near-bottom water in an east-west direction. The net bottom drift is to the northwest at 0.5 cm/sec. Suspended sediment concentrations average 10 mg/l, with storm-induced values to 30 mg/l. The baseline community data revealed a homogeneous, mature infaunal community dominated by the polychaete *Nephtys incisa* and the bivalve molluscs *Macula proxima* and *Yoldia limatula*.

8. The FVP disposal site was selected within the CLIS so as to minimize contamination from other sources, including relic disposal operations or ongoing disposal activities occurring during the study period. This was necessary to ensure a point source of contamination. The uniformity of physical, chemical, and biological properties of the disposal site prior to disposal allowed detection of changes in these properties due to the disposal of the dredged material. Finally, the stations used to study the biological effects in this study were selected along the primary axis of current flow to represent a gradient of potential exposure for the biota (Figure 2).

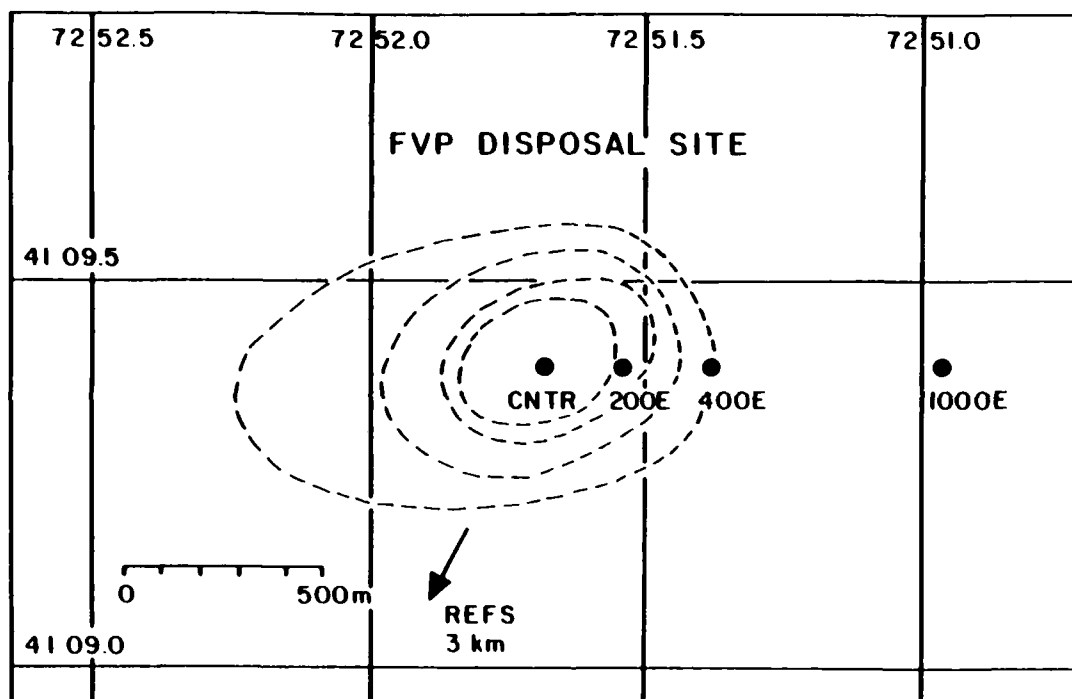


Figure 2. FVP sampling stations

9. The spatial scale of this study was near-field and limited to the immediate vicinity of the disposal site. A primary assumption was that the mound of dredged material constituted a point source of contamination. The temporal scale for the study was 4 years, which included a year of predisposal data collection to define seasonal patterns in the physical, chemical, and biological variables and 3 years of postdisposal data collection to address the objectives of the program and to evaluate the long-term impacts of the disposal operation on the surrounding benthic communities.

10. The dredging site was Black Rock Harbor (BRH), located in Bridgeport, Conn., where maintenance dredging provided a channel 46 m wide and 5.2 m deep at mean low water (Figure 1). Approximately 55,000 m³ of material was dredged during April and May 1983 and disposed in 20 m of water in the northeastern corner of the CLIS disposal site.

11. The dredged material from BRH contained substantial concentrations of both organic and inorganic contaminants (Rogerson, Schimmel, and Hoffman 1985). Polychlorinated biphenyls (PCBs) were present in the dredged material at a concentration of 6,4000 ng/g, and polynuclear aromatic hydrocarbons (PAHs) with molecular weights between 166 and 302 were present at concentrations ranging from 1,000 to 12,000 ng/g, respectively. Alkyl homologs of the PAHs were also present in the dredged material at concentrations between 1,000 and 13,000 ng/g. Inorganic contaminants of toxicological importance present in the dredged material include copper (2,900 µg/g), chromium (1,480 µg/g), zinc (1,200 µg/g), lead (380 µg/g), nickel (140 µg/g), cadmium (24 µg/g), and mercury (1.7 µg/g).

Project Scope

12. The FVP is unique among marine research studies for several reasons. The program objectives are directly focused on addressing specific limitations in the methodologies and interpretive framework of the current regulatory process. Among the program strengths were the following: (a) a suite of biological endpoints using the same material were developed and evaluated; (b) the biological tests represented different levels of biological organization; (c) the tests were conducted under both laboratory and field exposure conditions; (d) tissue residues were examined concurrently with measurements of biological effects; (e) the duration of the study was adequate to evaluate the use of community responses as a benchmark against which other biological responses could be compared; and (f) the project was a site- and waste-specific case study for the application and evaluation of the components of a risk assessment, including the development of methodologies for predicting and measuring field exposures in the water column and benthic compartments. Limitations of this study were: (a) only one dredged material was evaluated, which constrained certain types of comparisons; (b) the size of the study put limits on the extent to which any given objective was examined; and (c) the

resources allocated to determine field exposures were limited. The latter is particularly important because the laboratory-field comparisons and the risk assessment process both require accurate predictions of environmental exposures.

Laboratory-Field Comparisons

13. The field verification of laboratory test methods was designed to compare the exposure-response relationships measured in both the laboratory and the field. Exposure for the purposes of this discussion includes the total dredged material with all of its contaminants. Specific contaminants are used as "tracers" to verify the exposure environment, which is described in terms of BRH dredged material, and to illustrate exposure-response relationships between the laboratory and field. The specific contaminants are a subset of a comprehensive suite of chemicals analyzed in this study and were selected based upon their environmental chemistry and statistical representativeness. The use of specific contaminants in no way implies a cause-and-effect relationship between contaminant and response.

14. Exposure in open marine systems is characterized by highly dynamic temporal and spatial conditions and cannot be completely replicated in laboratory systems. Consequently, the approach chosen for this program was to develop laboratory exposure-response data using only general field exposure information.

Residue-Effect Relationships

15. Determining the relationship between contaminant tissue residues resulting from bioaccumulation and the biological responses measured is a principal objective of this program. Such relationships do not in any way imply cause and effect, but rather seek to determine the statistical relationship between an effect and any associated residues. The approach used is to determine specific contaminant residues in the tissues of the organisms as the result of exposure to the whole dredged material in both the laboratory and the field. These residues are determined at the same time that biological responses are being measured. Residue-effect relationships will be described and interpreted for both laboratory and field exposures.

Histopathology

16. One biological response evaluated during the FVP study was an investigation of the histological condition of tissues from organisms exposed to contaminated sediment in the laboratory and in the field. Bang (1980) and Sindermann (1979, 1980) highlighted the use of histopathology as a potential tool in predicting and estimating the impact of contaminants on aquatic species. Historically, histopathological examination of human and mammalian tissues has played an important role in clinical, forensic, human, and veterinary medicine. The use of this field as a predictive tool in the aquatic environment, however, is hampered by several factors, including a lack of laboratory and field data describing the relationship between contaminants and a given pathological condition, a poor understanding of the interaction between pollutants and particular disease agents (e.g., viruses), and the fact that no simple screening tool is available.

17. Histopathologic examinations evaluate the health of an organism on the basis of cellular and tissue architecture. The types of cellular changes noted and the degree of divergence from normal cell structure indicate the relative degree of injury to the organism. Abnormal histological conditions may interfere with normal physiological functions, reproductive capability, and survival.

18. Several studies underline the value in examining tissues from laboratory and field specimens in order to explain the underlying mechanisms for any effect observed in the whole organism. An example of the utility of histological examination is provided in a study in which *Fundulus heteroclitus* were exposed to cadmium at a concentration of 50 ppm (Gardner and Yevich 1970). Animals were collected for histological examination at various time intervals during the exposure period, and the following sequence of pathologic effects was noted. After 1 hr of exposure, extensive necrosis of the intestinal mucosa was observed, while necrosis of the uriniferous tubules was evident after 11 hr of exposure. Gill filaments, on the other hand, showed histopathologic changes only after 20 hr of exposure. Thus, the sequence in which tissues were affected was (a) the epithelium of the intestine, (b) the kidneys, and (c) the gills. The finding that the intestine rather than the gills was the first site of pathology was significant since many researchers at that

time postulated that the first site of toxic action for cadmium would be the gills.

19. In another study, Peters et al. (1981) examined stony corals exposed to the water-accommodated fraction of No. 2 fuel oil for a period of 3 months. Several detrimental histopathological effects were observed, including cellular degeneration and atrophy of tissue. These histopathological findings indicate that the oil exposure interfered with normal physiological functions.

20. Histological examination of organisms from the field has provided insights into the mode of toxicity evident in the collected organisms. Sindermann (1980) in a review of pathological effects of contaminants in marine organisms concluded that tumors and other histological abnormalities are more prevalent in species from polluted environments. Haensly et al. (1982) conducted an in-depth survey of the flat fish from the Brittany region of France impacted by the *Amoco Cadiz* crude oil spill. Among the histopathological changes present in fish collected from oil-contaminated estuaries but absent in fish from relatively clean sites were fin and tail necrosis, lamellar lesions in the gills, muscle fiber degeneration, and tubular degeneration of the kidneys. The etiology of the histopathological changes could not be fully attributed to contact with oiled sediments; however, contaminant exposure seemed to be an important factor in the presence of these diseases.

21. In a 5-year study of Long Cove, Searsport, Maine, an area contaminated with JPS jet fuel and No. 2 fuel oil, Yevich and Barszcz (1977) observed a 1- to 22-percent incidence of gonadal neoplasms in the soft shell clam *Mya arenaria* collected from various stations in the cove. Gonadal tumors were not detected in *M. arenaria* collected from contaminant-free sites located in the region. A direct causal link between oil and carcinogenesis could not be established because laboratory exposures of soft shell clams could not induce the gonadal neoplasms. Brown (1980) in a further study of the incidence of gonadal neoplasms in soft shell clams demonstrated that the etiology of this disease was due to the transfer of a virus between infected and healthy specimens. The presence of contaminants, however, does appear to play a role in disease transmission by increasing the susceptibility of the clams to viral infection and neoplasm development.

22. In the present study, cells and tissues of the polychaete *Nereis incisa* and the blue mussel *Mytilus edulis* exposed in the field were examined

by light microscope for histopathology. These results were then compared with results from individuals of the same species exposed to laboratory simulations of environmental exposures from which the field organisms had been collected. Yevich et al. (1986) investigated the appearance of histological changes in a number of aquatic species in the laboratory documentation phase of the FVP. The results of that study suggested that the occurrence of some pathological responses are correlated with increases in the concentration of contaminated material in the exposure environment.

PART II: MATERIALS AND METHODS

Laboratory Methods

Sediment collection

23. Two sediment types were used to conduct laboratory tests for the field verification studies. The reference (REF) sediment was collected from the South Reference site in Long Island Sound (40°7.95' N and 72°52.7' W) by Smith-MacIntyre grab (0.1 m²), press sieved through a 2-mm sieve, and stored at 4° C until used. Prior to dredging, contaminated sediment was collected from Black Rock Harbor (41°9' N and 73°13' W) with a gravity box corer (0.1 m²) to a depth of 1.2 m, thoroughly mixed, press sieved through a 2-mm sieve, and refrigerated (4° C) in barrels until used. Details of sediment collection and storage procedures may be found in Rogerson, Schimmel, and Hoffman (1985). In all experiments, sediments were allowed to reach test temperature and were mixed prior to use.

Organism collection and holding

24. *Mytilus edulis*. Two separate experiments were completed using oxidized REF and BRH sediments. Mussels were collected from the Narragansett Bay REF population (71°24.0' W by 41°29.4' N) with a scallop dredge from a depth of 10 m. Collection information for each experiment is listed in Table 1. The animals were sorted to obtain a size range of 50- to 55-mm shell length and were acclimated in flowing unfiltered Narragansett Bay seawater at a rate of 1° to 15° C/day.

Table 1

Collection Information for the Mussels Used in the Laboratory Experiments

<u>Experiment</u>	<u>Collection Date</u>	<u>Experiment Begun</u>	<u>Temperature °C</u>	<u>Salinity g/kg</u>
1	17 Jan 85	05 Feb 85	2.0	30.0
2	22 Feb 85	12 Mar 85	5.0	30.0

25. *Nephtys incisa*. *Nephtys incisa* for laboratory studies were collected with a Smith-MacIntyre grab sampler (0.1 m²) at the South Reference site (Figure 1). Collection information for each experiment is listed in Table 2.

Table 2
Collection Information for the *N. incisa*
Used in the Laboratory Experiments

<u>Experiment</u>	<u>Duration days</u>	<u>Collection Date</u>	<u>Experiment Start Date</u>	<u>Temperature °C</u>	<u>Salinity g/kg</u>
1	10	30 Oct 84	10 Dec 84	15	28.0
2	28	27 Feb 85	12 Mar 85	1	28.5
3	42	23 Apr 85	3 May 85	10	29.3

The sediment containing the *N. incisa* was brought to the laboratory, where it was sieved and the *N. incisa* were picked and sorted by size. Tests were conducted with adult specimens. These individuals were placed in REF sediment in flowing seawater and were acclimated at a rate of 1° to 20° C/day. They were fed powdered prawn flakes, *ad libitum*, during this period.

Suspended sediment dosing system

26. Laboratory studies required the construction of two identical sediment dosing systems to provide either BRH or REF material as suspended sediment simultaneously. Each dosing system (Figure 3) consisted of a cone-shaped slurry reservoir placed in a chilled fiberglass chamber, a diaphragm pump, a 4-ℓ separatory funnel, and several return loops that directed the particulate slurry through dosing valves. The slurry reservoir (40 cm in diameter by 55 cm high) contained 38 ℓ of slurry composed of 36 ℓ of filtered seawater and 2 ℓ either BRH or REF sediment. The fiberglass chamber (94 cm long by 61 cm wide by 79 cm high) was maintained between 4° and 10° C, using an externally chilled water source to minimize microbial degradation during the test. Polypropylene pipes (3.8-cm diameter) extended to the bottom of the reservoir cones and were connected to pumps (16- to 40-ℓ/min capacity) fitted with Teflon diaphragms. These pumps were used to circulate the slurry while minimizing abrasion that might produce changes in the physical properties (e.g., particle size) of the material.

27. The slurry was pumped up to separatory funnels and returned via an overflow to the reservoir through polypropylene pipes. The separatory funnel provided the constant head pressure needed to circulate the slurry through Teflon tubing to the dosing valves, where the slurry was mixed with seawater

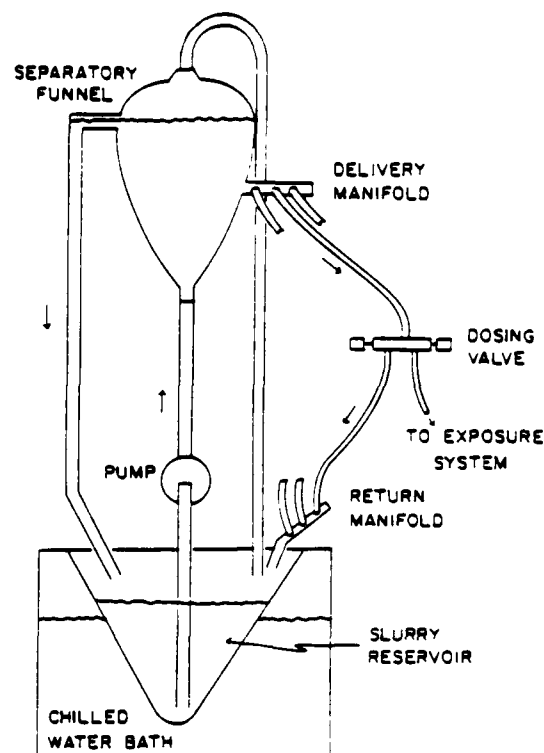


Figure 3. Suspended sediment dosing system

to provide the desired concentrations for the toxicity tests. Narragansett Bay seawater filtered (to 15 μ) through sand filters was used.

Suspended sediment oxidation system

28. The REF and BRH sediments used in these experiments were oxidized prior to introduction into the dosing system. The objective of this portion of the FVP was to evaluate the relationship between biological endpoints measured in the laboratory and the field. The field collections of sediment indicated rapid oxidation of the surficial BRH sediments on the disposal mound. Because the most likely source of particulate contaminants in the water column was the oxidized surficial sediment, it was decided that laboratory exposures would be conducted with BRH sediment that had been oxidized in a consistent manner.

29. To obtain consistent states of oxidation for both REF and BRH sediments, 2 l of sediment was transferred to an inverted polycarbonate carboy and diluted to 19 l with filtered natural seawater at room temperature and aerated for 3 to 4 days (Figure 4). The contents were transferred to the composite dosing system reservoir and diluted to 38 l with natural seawater. Chemical

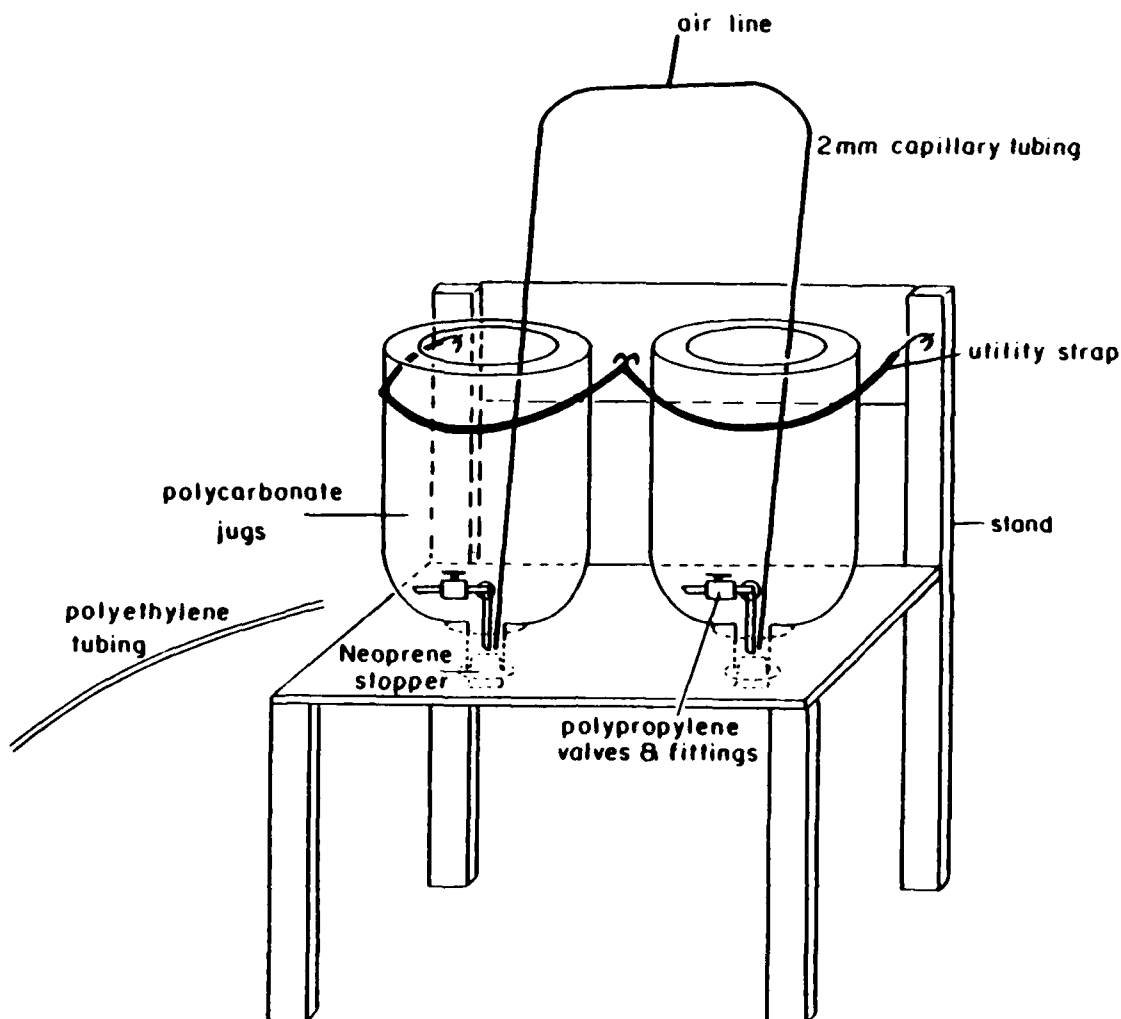


Figure 4. Suspended sediment oxidation system

oxygen demand measurements indicated that this time period was sufficient to satisfy the immediate oxygen demand of the sediments.

Exposure system

30. *Mytilus edulis*. An exposure system was constructed to provide a constant concentration of suspended sediment to mussels in the laboratory. This system consisted of recirculating loops from the suspended sediment dosing system; these loops were connected to a dosing valve at each exposure chamber. The concentration of total suspended particulates was maintained at approximately 12 mg/ml in both the REF and BRH loops. The exposure system was capable of delivering either REF or BRH sediment directly into each mussel exposure chamber via a dosing valve. The combined use of a REF and a BRH

dosing valve at an exposure chamber allowed delivery of a mixture of the two sediments. The percent concentrations of BRH and REF sediment varied between treatments; however, a total suspended sediment concentration of approximately 10 mg/l (dry weight) was maintained in all five laboratory exposure treatments. This concentration was chosen because it approximated the background field suspended sediment concentration present at the CLIS disposal site.

31. Each mussel exposure chamber was equipped with a transmissometer, an instrument capable of measuring light attenuation due to suspended sediment in the chamber (Figure 5). The dosing valves for each treatment were

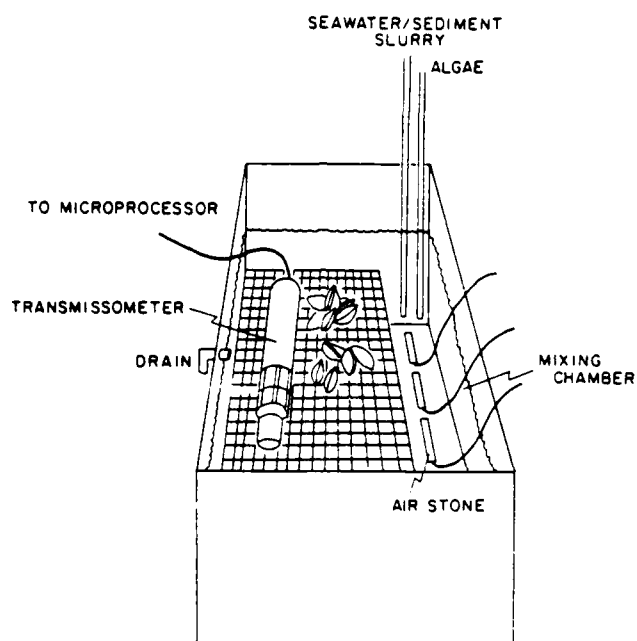


Figure 5. Laboratory exposure system for *M. edulis*

controlled by a transmissometer-microprocessor feedback loop (Sinnott and Davis 1983). The transmissometer in each chamber was calibrated by regressing suspended sediment concentrations, which were measured by filtration onto glass fiber filters, with the transmissometer units displayed on a microprocessor. A transmissometer value that corresponded with the desired suspended sediment concentration of 10 mg/l for each chamber was calculated. As the mussels removed suspended sediment, the microprocessor opened dosing valves to deliver additional suspended sediment at 2-min intervals. In this manner, suspended sediment concentrations were maintained at the desired values (± 10 percent). The transmissometer circuit was also connected to a strip

chart recorder, which allowed the operation of the system to be monitored continuously. Each chamber was aerated with three 25- by 2.5-cm air stones to provide sufficient oxygen and to ensure even distribution of suspended particulates (Figure 5).

32. In addition to the suspended sediment, food in the form of the unicellular alga *Isochrysis galbana* was supplied to each exposure chamber. Periodic measurements were made of mussel clearance rates in each chamber to determine the volume of algae required to maintain an algal concentration of 0.5 mg/l. This concentration constituted an adequate maintenance ration for the mussels. Algae were added at 5-min intervals by means of a peristaltic pump. All experiments were conducted at 15° C with filtered seawater that flowed through each experimental chamber at a rate of 0.4 l/min. Each chamber was cleaned every other day.

33. The purpose of the laboratory experiments was to expose *M. edulis* to a range of BRH concentrations that may have been present in CLIS and to assess the biological effect on these organisms. *Mytilus edulis* were exposed for approximately 1-month periods at the CLIS disposal site; therefore, exposures of similar duration, 28 days, were used for the laboratory exposures.

34. At the start of both experiments, 150 mussels were placed into each chamber. *Mytilus edulis* were sampled at time 0 for determination of initial tissue residue concentrations and for histopathological (HP) testing.

35. Experiment 1 consisted of three exposure treatments: 100-percent, 50-percent, and 0-percent BRH suspended sediment. *Mytilus edulis* were removed from each treatment on Day 14 for chemical and biological analysis. Experiment 1 was terminated at Day 14 because adverse biological effects (e.g., reduced filtration rate) were observed in both treatments containing BRH sediment.

36. Experiment 2 was conducted with lower concentrations of BRH suspended sediment. Exposure treatments of suspended sediment in Experiment 2 were 30-percent, 10-percent, and 0-percent BRH. Fifteen organisms were removed on Days 7, 14, 21, and 28 for tissue residue analysis. Whole water chemistry samples were taken within 1 day of organism sampling. Dissolved and particulate water samples were taken within 24 hr of Days 0, 14, and 28. Mussels were sampled on Days 14 and 28 for biological analysis. In addition, a water sample was taken on Day 29 to evaluate the performance of the system without any mussels in the exposure chambers.

37. The operation of the system (dosing valves, flow rates, etc.) was monitored daily. Experiments using the 100- and 0-percent BRH treatments required only one dosing valve each, while the 50-percent BRH treatments required a REF and BRH valve that delivered equal amounts of suspended material. A strip chart record for each treatment indicated that the dosing valves were operating properly. The 10- and 30-percent BRH treatments also required two dosing valves per treatment; however, the REF and BRH dosing valves delivered different amounts of suspended material. This was accomplished by adjusting the delivery volume of each valve. The mixture of BRH and REF material was checked daily and adjusted if necessary.

38. Nephtys incisa. In the laboratory tests with *N. incisa*, the dosing system was set to maintain nominal concentrations of 200 mg/l (dry weight) of suspended sediments with seawater flow rates producing five volume replacements per exposure chamber per day. These flow rates meet the minimum recommended by the American Society of Testing Materials (ASTM 1980) and were intended to maximize residence time of the suspended sediments in the exposure chambers.

39. A suspended sediment proportional diluter (Figure 6) was used to mix the small quantities of concentrated sediment slurries (10 to 20 g/l) from the sediment dosing system with filtered seawater to produce diluted sediment suspensions in the milligrams-per-litre range. It then combined slurries of different types (e.g., REF and BRH sediment suspensions) proportionally to maintain the same concentration of suspended sediment with different ratios of the two sediments.

40. The exposure chamber for *N. incisa* is illustrated in Figure 7. Polycarbonate bottles (19 l) used commercially for shipping spring water were cut off at the top. REF sediment (2 l/chamber) was added to a depth of 4 cm, and Plexiglas strips were inserted into the sediment, dividing it into pie-shaped sections. This permitted subsampling without disturbing the entire chamber. Each chamber was filled with filtered seawater at 20° C. After the sediment in the chambers was permitted to settle and equilibrate for about 4 hr, *N. incisa* were added, and an additional 2 hr were allowed for the worms to burrow into the sediment. The delivery tubes from the proportional diluter were then put in place, and a low pressure airlift was turned on to keep the dosed sediment in suspension. This system allowed very little sediment deposition during the course of experiments. Excess seawater was permitted to

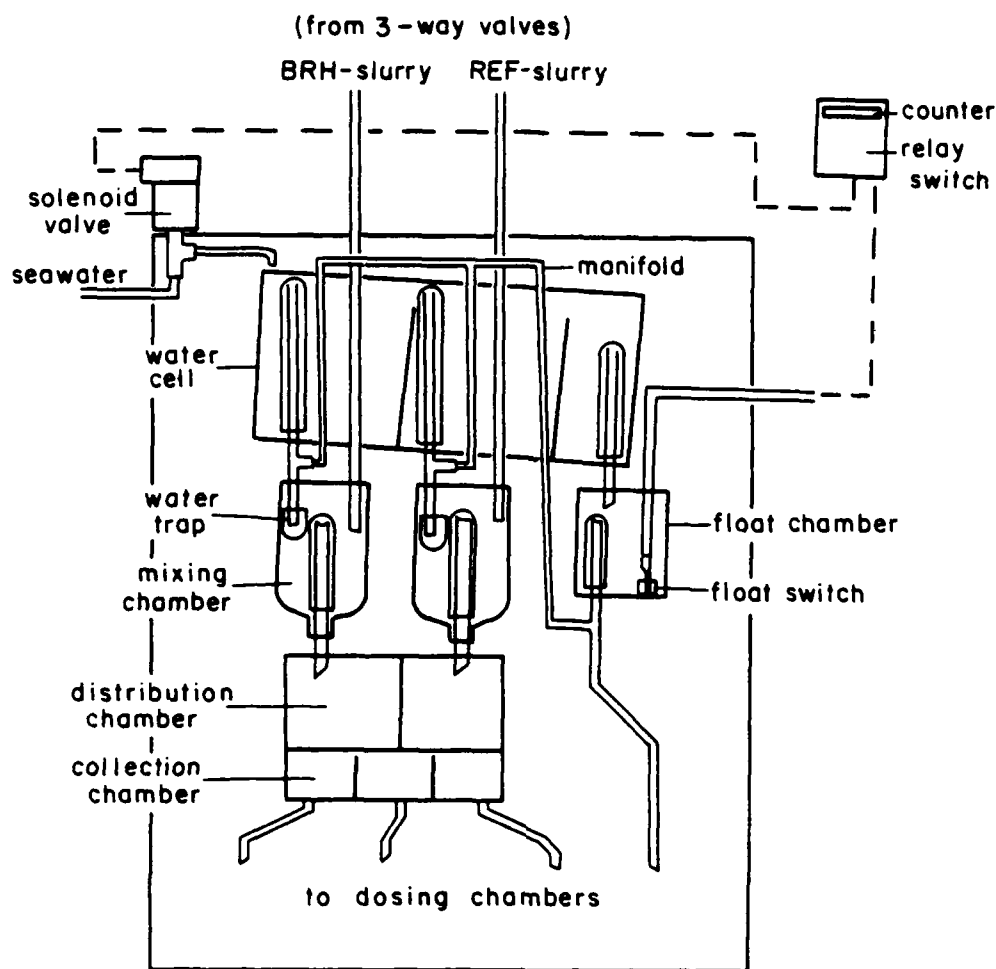


Figure 6. Proportional diluter used to deliver suspended sediment to the *N. incisa* exposure chambers

overflow the brim of each chamber. Earlier experiments indicated that once the worms burrowed into clean reference sediment, they would not attempt to escape. Therefore, the chamber design used here was considered acceptable. Two chambers were used for each of the three treatments for a total of six chambers per experiment. The two chambers did not represent replicates, but were used to accommodate enough worms for chemical and biological analysis in each experiment.

41. Histopathological examinations were conducted in two experiments during this phase of the FVP. These experiments lasted 28 and 42 days, respectively, and had exposure conditions of 100-, 50-, and 0-percent BRH suspended sediment. The 42-day experiment provided time series sampling for the three-exposure conditions. Worms were removed at time 0, Day 28, and

DOSING CHAMBER

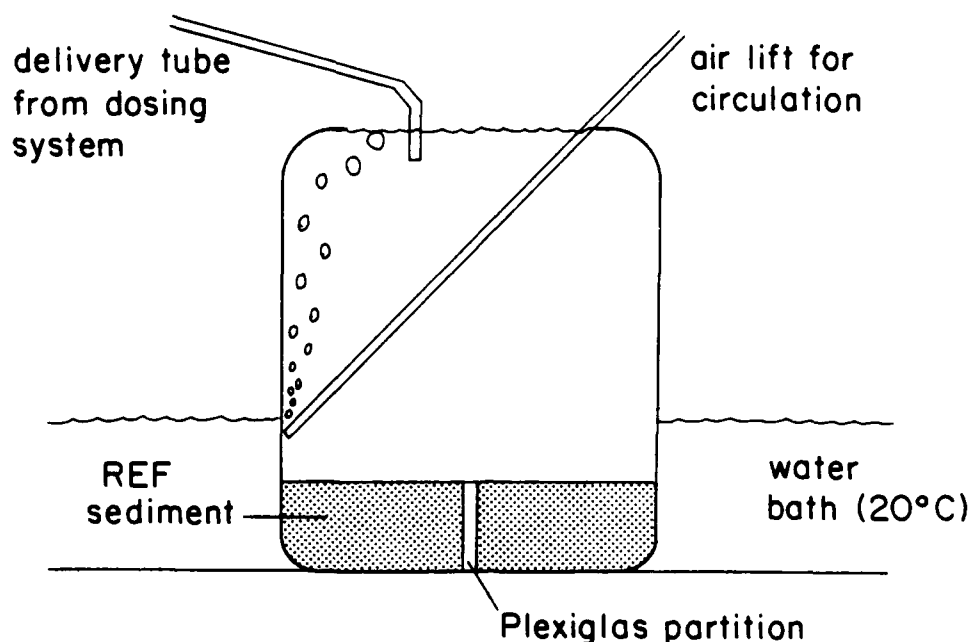


Figure 7. *Nephtys incisa* exposure chamber

Day 42. This experiment was supported with chemical analyses of the seawater and *N. incisa* at each sampling. *Nephtys incisa* were collected on a sieve after removal of a pie-shaped aliquot of bedded sediment from each chamber. Clean REF sediment, without *N. incisa*, was returned to the vacated section to maintain the integrity of the exposure chamber.

42. Suspended sediment, temperature, and salinity were measured routinely during each experiment. Dissolved oxygen (DO) concentrations were not expected to be a problem because of the large volume of the chamber and the use of an airlift. However, DOs were determined once during each experiment and never differed significantly from expected saturation levels. The worms were fed 100 mg of powdered prawn flakes per chamber per day for the duration of each experiment.

Histological methods

43. Standard histological methods for aquatic animals were applied in these studies (National Academy of Sciences 1980; Yevich and Barszcz 1981; Yevich et al. 1986). Major organ systems of each species were examined under a light microscope for evidence of histopathological changes that might be

attributable to exposure to BRH material. In general, detailed observations of the appearance of the organisms were made prior to fixation, and the date, species, areas of collection, type of study, and other pertinent data were recorded. Live or freshly sacrificed animals were then placed in fixative for 15 to 40 min to firm the tissues. Following this, the organisms were removed, sectioned (e.g., sagittally, transverse, etc.), and returned to the fixative. At the completion of fixation, the tissues were given a final trimming as necessary, washed to remove excess fixative, and then stored in S-29 dehydrating reagent.

44. To prepare the tissues for penetration by paraffin, the cut sections were dehydrated in S-29 and cleared in UC-670, Technicon's dehydrating and clearing reagents, on the Autotechnicon tissue processor. Following paraffin infiltration, the tissues were embedded into paraffin blocks. Tissue sections were cut at 6 μ on a rotary microtome, mounted on slides, and stained with Harris hematoxylin and eosin. Table 3 outlines the amount of time necessary for each of the major steps involved in tissue processing (Yevich and Barszcz 1981, Yevich et al. 1986). All blocks were saved and recut as necessary to confirm observed abnormalities.

Table 3
General Procedures for Processing Tissues

<u>Procedure</u>	<u>Time Necessary</u>
Initial fixation	20-30 min
Initial trimming	As required
Final fixation	2 - 24 hr
Final trimming	As required
Washing in water	16 - 24 hr
Storage of tissues	Until processed
Dehydration, cleaning, and infiltration	4 - 10 hr
Embedding	As necessary
Sectioning	As required
Staining	As required

45. At the end of the exposure period, mussels to be used for histopathological examination were prepared in the following manner. The shell halves were opened by forcing a sharp clam knife between the two valves slightly above the byssus threads so that the tip of the knife was between the mantle and the shell. With a sweeping motion, the muscle and mantle were cut loose from the shell. Mussels were trimmed by cutting the body mass sagittally into four sections. The following conditions were noted while fixing and trimming: (a) malformation, especially in the gills and body mass; (b) parasites, both external and internal; (c) firmness of tissue; (d) changes in color of the internal organs, such as the digestive diverticula and gonadal tissue; and (e) cyst and tumor formation. Fixation in Helly's (Yevich et al. 1986), dehydration (S-29), clearing (UC-670), paraffin infiltration, embedding, sectioning, and staining were accomplished with the Autotechnicon.

46. Based on the trimming techniques, four blocks were prepared for each mussel. Two sections from each block, cut at 6 μ , were put on each slide. All blocks were saved and recut as needed to provide tissue for the special staining techniques used to clarify histopathological findings (Yevich and Barszcz 1981). The slides allowed examination of representative samples of all organs and tissues, including the reproductive tract, the cardiovascular system (auricle, ventricle, and pericardial wall), the gills (cilia and mucous secretory cells), the kidneys, the gastrointestinal tract (the labial palps, the esophagus, the stomach, the intestine and digestive diverticula ducts and tubules), the byssus organ, the muscles, and the connective tissue.

47. Following the exposure period, the worms were sieved from the sediment, visually observed, and then placed in Helly's fixative (Yevich et al. 1986). After initial fixation, the worms were cut sagittally into sections approximately 3 cm long. While fixing and trimming the worms, additional observations were made for the following conditions: (a) discoloration of the epidermis, (b) ulcerations of the epidermis, (c) malformation of the parapodia, and (d) presence of external and internal parasites. Fixation time was approximately 14 hr. Following fixation, the worm sections were washed, stored in 70-percent ethanol, and processed on the Autotechnicon tissue processor. After embedding, tissues for three slides were cut from each block and stained with Harris hematoxylin and eosin. All major tissue types and organ systems were examined, including epidermis, muscle, gastrointestinal tract, nervous system, reproductive tract, and mucous secretory cells.

Field Methods

Organism collection and holding

48. *Mytilus edulis*. All mussels used in the field studies for the FVP were collected by scallop dredge from Narragansett Bay. In general, *M. edulis* were collected 1 to 2 days prior to field deployment to Long Island Sound. They were returned to the laboratory, where 100, 5- to 7-cm organisms were sorted and placed into each polyethylene basket. All baskets were placed in holding tanks of flowing unfiltered seawater until deployed in the field.

49. *Nephtys incisa*. *Nephtys incisa* for field studies were collected at stations REFS, 1000E, 400E, 200E, and CNTR. Station locations were marked with buoys for the duration of this project. While the boat was anchored, a Smith-MacIntyre grab sampler (0.1 m^2) was used to collect bottom sediments. These sediments were wet sieved on deck (nested sieves of 2- and 0.5-mm mesh size), and organisms were collected. On each sampling date, *N. incisa* were collected for biological measurements. Specimens for histopathology were prepared immediately on the boat.

Exposure

50. *Mytilus edulis* deployment and retrieval. *Mytilus edulis* were deployed at CNTR, 400E, 1000E, and REFS at the CLIS disposal site (Figure 2). The physical arrangement of each station is detailed by Phelps and Galloway (1980). In short, each station consisted of a surface buoy attached by cable to a concrete mooring on the bottom, with two smaller satellite moorings attached to the larger main mooring. A subsurface buoy was attached to each small mooring, from which the mussel baskets were hung 1 m above the bottom. Two baskets were attached to each subsurface buoy at each deployment.

51. The deployments of *M. edulis* at the CLIS disposal site are summarized in Table 4. Mussels were deployed at each station for a period of 1 month predisposal to collect baseline data (Cruise Number T - 04). A second deployment occurred during disposal operations, except that no mussels were placed at the CNTR station ($T = 0$, $T + 2$). Mussels were deployed for 1-month periods over the next 3 months ($T + 8$, $T + 12$, $T + 16$) and then on a quarterly basis for the next year ($T + 23$, $T + 40$, $T + 55$, and $T + 74$). In addition, several sets of mussels were left at each station for 7 months ($T + 22$). The Cruise Number designation is not related to the length of deployment.

52. *Mytilus edulis* were retrieved from the subsurface buoys by divers.

Table 4
Cruise Number, Deployment Date, Retrieval Date, and Length of
Deployment for Mussels Transplanted to CLIS

<u>Cruise Number</u> <u>Weeks**</u>	<u>Deployment Date</u>	<u>Retrieval Date</u>	<u>Length of Deployment</u>
T - 4	16 Mar 83	22 Apr 83	1 month
T = 0*	22 Apr 83	24 May 83	1 month
T + 2	23 Apr 83	07 Jun 83	6 weeks
T + 8	07 Jun 83	13 Jul 83	1 month
T + 12	13 Jul 83	10 Aug 83	1 month
T + 15	10 Aug 83	06 Sep 83	1 month
T + 22	16 Mar 83	18 Oct 83	7 months
T + 27	06 Sep 83	29 Nov 83	3 months
T + 43	29 Nov 83	20 Mar 84	3 months
T + 55	18 Oct 83	05 Jun 84	8 months
T + 74	12 Jun 84	17 Oct 84	4 months

* T = 0 refers to the termination of disposal activities at the FVP site on 18 May 83.

** The Cruise Number Weeks are not related to the Length of Deployment.

Mussels used for chemical analysis were frozen immediately. The remaining mussels were maintained in tanks of flowing seawater on deck and returned to ERLN later that day and held in flowing unfiltered seawater overnight. The next morning, mussels were distributed to the appropriate investigators for biological analyses.

53. Mytilus edulis field exposures via tissue residues. Exposure conditions present in the field during each mussel deployment were not as well characterized as they were in the laboratory studies. As a result, the description of *M. edulis* exposure to BRH material in the field is more qualitative than quantitative and will be presented in two parts. First, a prediction of field exposure is based on mussel tissue residues. The relationship between exposure to BRH sediments and tissue residues was determined in the laboratory experiments. Tissue residues from the 0-, 10-, and 30-percent BRH treatments at 28 days were regressed against measured BRH exposure concentrations (0-, 1.5-, 3.3-mg/l) from the same exposures. In order to correct for

background residues in the laboratory, the PCB concentration of the 0-percent BRH treatment was subtracted from the others prior to regression analysis. The resultant equation, $\text{mg/l BRH material} = (\text{PCB residue} \times 0.000965) - 0.0019$, ($R^2 = 0.99$), was then used to calculate the average sustained concentration of BRH material necessary to achieve the residue value obtained in the field.

54. The estimated BRH exposure levels in the field were determined by substituting the mussel PCB tissue residue concentration directly into the above equation. This estimate was assumed to represent an upper range of suspended BRH material present. A second estimate was determined by first subtracting the PCB concentration in mussels at the REFS station from the other stations during that collection. This removed the Long Island Sound (LIS) background PCB levels from the estimates, and thus was assumed to represent a lower range of BRH present in CLIS. This procedure was completed for each collection date and station that mussels were retrieved.

55. Estimated exposure via water chemistry data. A second estimate of exposure was generated from the PCB and copper (Cu) concentrations in the whole water samples collected during various postdisposal cruises. The concentration of BRH material that would have to be present to produce these levels was determined by dividing the concentration of PCB and Cu present in the barrel material collected from BRH (2,900 $\mu\text{g/g}$ and 6,400 ng/g for Cu and PCB, respectively). A range of exposures also was calculated for the water chemistry data; estimated BRH material was determined with and without subtracting the concentration at the REFS station.

56. *Nephtys incisa* field exposures via tissue residues. The purpose of exposure assessment is to determine, through predictions or direct measurement, the temporal and spatial range of exposure concentrations experienced by populations of interest. The exposure conditions present in the field for *N. incisa* were not as well characterized as they were in the laboratory studies. As a result, the description of *N. incisa* exposure to BRH material in the field is more qualitative than quantitative. First, a prediction of field exposure can be made on the basis of worm tissue residues. The relationship between exposure to BRH sediments and tissue residues was determined in the laboratory experiment. Tissue residues of PCBs as A1254 from the 0-, 50-, and 100-percent BRH treatments at 42 days were plotted against BRH exposure concentrations. This relationship was then used to estimate field exposure

conditions based on tissue residues of PCBs in field-collected worms. Inherent in this approach is the assumption that organisms have analogous bioaccumulation patterns in the laboratory and field.

57. *Nephtys incisa* field exposures via physical data. The second analysis describes a calculation that predicts the maximum total suspended solids concentrations from 1 m above the bottom to the sediment-water interface. This analysis assumes that the total suspended solids are composed of BRH sediments, and it represents a worst case or upper bound prediction. A third more realistic model calculates the probable amount of BRH sediment exposure at the sediment-water interface based upon the actual contaminant concentrations of the surficial sediments for each sampling station and date. This analysis assumes that resuspension of the surface sediment is the primary source of the total suspended solids at the sediment-water interface.

58. The equation used to calculate total suspended solids concentrations from the sediment-water interface up to 1 m above the bottom is described below:

$$C_z = C_m \left[1 + (C_o - 1)e^{-kz} \right] \quad (1)$$

where

C_z = total suspended solids concentration at distance z

C_m = total suspended solids concentration at 1 m above the bottom

C_o = enrichment factor (C_z/C_m when $z = 0$)

$-k$ = rate of change in total suspended solids concentration

z = distance in meters from the bottom

Given the total suspended solids concentration at 1 m above the bottom, the equation predicts an exponential increase in suspended solids concentration at distances from 1 m above the bottom to the sediment-water interface.

59. The total suspended solids concentrations for these analyses were selected to represent average and storm conditions that were empirically determined from an in situ continuous monitoring platform deployed 1 m above the bottom at the disposal site (Bohlen and Winnick 1986, Munns et al. 1986). Enrichment factors were likewise empirically determined from acoustic profilometer data collected between the sediment-water interface and 1 m above the bottom (Bohlen and Winnick 1986, Munns et al. 1986).

Maximum upper bound
estimate: predredging data

60. For the purpose of the maximum upper bound analyses, it is assumed that the exposed populations are located off the mound and aligned with the mean direction of current flow. The route of contaminant exposure is assumed to be through the transport of resuspended BRH sediments. These total suspended solids are composed of resuspended LIS sediments, as well as BRH sediment resuspended from the disposal site. Since the intent of these analyses is to create a maximum upper bound set of exposure conditions, it was assumed that the suspended solids concentration was composed in total (100 percent) of resuspended BRH sediment.

Probable exposure
estimate: postdisposal data

61. It was not within the scope of this program to provide a continuous temporal record of the percent contribution of BRH sediments to the total suspended solids load. Consequently, a second set of analyses was designed to estimate the percentage of BRH sediment that could have comprised the total suspended solids concentration at the sediment-water interface for each station and to determine how these concentrations changed with time throughout the study. The proportions of BRH dredged material in the surficial sediments at each station and date were estimated by comparing the concentrations of selected contaminants measured in the 0- to 2-cm layer of sediment cores collected, postdisposal, at the FVP site. These field concentrations were compared with the barrel concentrations to determine a percentage as follows:

$$\text{Percentage BRH Sediment} = [(C - \text{REF}) / (\text{BRH} - \text{REF})] \times 100 \quad (2)$$

where

C = concentration of contaminant in the dredged sediment

REF = concentration of contaminant in REF sediment

BRH = concentration of contaminant in BRH sediment (barrel)

The percentage BRH sediment values were calculated for each station and date using the 11 different contaminants, the details of which are shown in Appendix B, Tables B1-B13. To achieve a BRH suspended sediment concentration that reflects the surficial sediment contaminant levels for each station and date, the total suspended solids concentrations predicted for the sediment-water interface were multiplied by the estimated proportions of BRH sediment.

Chemical Methods

Analytical methods

62. The analytical methods used in this study are presented here in summary form. More detailed descriptions of the analytical methods are available in Lake, Hoffman, and Schimmel (1985). Most of these methods represent extensive modifications of USEPA standard methods developed for freshwater and wastewater samples. It was necessary to modify these methods to analyze the types of matrices in this study. These methods were intercalibrated to ensure the quality of the data.

Organic sample preparation

63. Samples of sediment, suspended particulates, and organisms were extracted by multiple additions of increasingly less polar organic solvents using a tissue homogenizer. These mixtures were separated by centrifugation between additions; polar solvents were removed by partitioning against water; and the extracts were desulfured with activated copper powder when required. The extracts were then passed through a precolumn containing activated silica gel. Samples of both filtered and unfiltered seawater were solvent extracted in separatory funnels, and the extracts were saved. Foam plugs containing the dissolved organic contaminants from water samples were extracted with organic solvents. All of the above extracts were subjected to column chromatography on deactivated silica gel to separate analytical fractions and were volume reduced carefully prior to analysis.

Organic analysis

64. Electron capture gas chromatographic analyses for PCBs were conducted on a Hewlett-Packard 5840 gas chromatograph equipped with a 30-m DB-5 fused silica column. Samples were quantified against an Aroclor 1254 standard because the distribution of PCB congeners in the dredged material closely matched that distribution, as did the distribution in organisms at steady-state.

65. Gas chromatograph/mass spectrometric analyses were conducted with a Finnigan Model 4500, also equipped with a 30-m DB-5 fused silica capillary column. The mass spectrometer was operated through a standard lucos data system and was tuned at all time to meet USEPA quality assurance specifications.

66. All instruments were calibrated daily with the appropriate standards. The concentrations of the standards used were chosen to approximate

those of the contaminants of interest, and periodic linearity checks were made to ensure the proper performance of each system. When standards were not available, response factors were calculated using mean responses of comparable standards. Blanks were carried through the procedure with each set of samples, and reference tissue homogenate was analyzed with every 12 to 15 tissue samples.

Organic data compression

67. As stated above, PCBs were quantified as Aroclor 1254 because the sample patterns closely resembled that profile. This allowed a convenient way of reporting these data without treating the voluminous data that would have resulted from measuring some 55 congener peaks by electron capture detector. Likewise, a method was sought to summarize the PAH data. Appendix A lists the 35 individual PAH parent and alkyl homolog compounds and groups of compounds measured in this study. Each PAH of the same molecular weight, both parents and alkyl homologs, can be summed to yield 9 PAH parent sums and 5 alkyl homolog sums. Although useful, this only reduced the data to 14 PAH variables; this reduction was not sufficient. Since the distribution of PAHs differed greatly in both quantity and quality between LIS and the BRH dredged material, statistics that would retain significant quantitative and qualitative information were sought. The quantitative statistic chosen was the simple SUM of all measured PAHs, and a qualitative descriptor was chosen by analogy with the center of mass concept from elementary physics and called a centroid (CENT):

$$\text{SUM} = \sum [C(i)] \quad (3)$$

$$\text{CENT} = \frac{\{\sum [C(i) \times \text{MW}(i)]\}}{\text{SUM}} \quad (4)$$

where

$C(i)$ = concentration of i^{th} PAH from molecular weight 166 through 302, including both parent and alkyl homologs

$\text{MW}(i)$ = molecular weight of i^{th} PAH from 166 through 302, including both parent and alkyl homologs.

In this case, CENT describes the "center of mass" of the PAH distribution and is in units of molecular weight. It is the concentration-weighted average molecular weight of any particular PAH distribution. Using this statistic, one

is able to readily distinguish two different sources of PAH distributions, one with predominately heavy molecular weight pyrogenic compounds and one with lighter molecular weight petrogenic compounds. These distributions are typically found in LIS at REFS and in BRH, respectively. A major value to this statistic is that it enables one to readily distinguish these two sources when their concentrations are nearly equal. The formulas for calculating these and 178 alkyl homologs are shown in Appendix A. Because distributions of both parents and homologs were measured, SUMs and CENTs of both parents and homologs were calculated as well. These were defined as PSUM, PCENT, HSUM, and HCENT. By definition,

$$\text{SUM} = \text{PSUM} + \text{HSUM} \quad (5)$$

and

$$\text{CENT} = \frac{(\text{PSUM} \times \text{PCENT}) + (\text{HSUM} \times \text{HCENT})}{\text{SUM}} \quad (6)$$

It should be noted that dibenzothiophene and its alkyl homologs are not included in these calculations because they are not PAHs.

Inorganic sample preparation

68. Sediment was prepared for inorganic analysis by elution at room temperature with 2N HNO_3 . The samples were filtered through Whatman #2 filter paper. Organisms were totally digested in concentrated HNO_3 at 60° C and filtered through Whatman #2 filter paper.

69. Cadmium, nickel, lead, and copper were concentrated and separated from both the unfiltered and filtered seawater fractions by coprecipitation (Boyle and Edmond 1975). The remaining metals (chromium, iron, manganese, and zinc) were analyzed by heated graphite atomization atomic absorption (HGA-AA) via direct injection. Samples of suspended particulates on Nucleopore (0.45- μ) filters were eluted with 2N HNO_3 and analyzed by HGA-AA.

Inorganic analysis

70. All flame atomization atomic absorption (FA-AA) was conducted with a Perkin-Elmer (Model 5000) atomic absorption spectrophotometer. All heated graphite atomization atomic absorption (HGA-AA) determinations were conducted with Perkin-Elmer Model 500 or 2100 HGA units coupled to Perkin-Elmer

Model 5000 or 603 atomic absorption instruments, respectively. The Model 5000 AA was retrofitted with a Zeeman HGA background correction unit, and the Model 603 was equipped with a D2 arc background correction system.

71. The FA-AA and HGA-AA instrument operating conditions are similar to those described in "Methods for Chemical Analysis of Water and Wastes" (USEPA 1979) and those in the manufacturer's reference manuals. The AA instruments were calibrated each time samples were analyzed for a given element. Sample extracts were analyzed a minimum of twice to determine signal reproducibility. Quality assurance checks, conducted after every 15 samples, were analyzed by the method of standard addition and by analyzing one procedural blank.

Contaminant selection

72. Chemical analyses performed in this study characterize the organic and inorganic constituents in the dredged material, provide information on the laboratory and field exposure environments, provide insight into the processes governing contaminant movement within and between environmental compartments, and determine which contaminants were accumulated by organisms. Historically, bulk sediment analyses have been used to characterize dredged material. More recently, dredged material must be analyzed for USEPA's priority pollutants to determine if hazardous substances are present and if so in what concentrations. While both of these approaches were used in this study, neither addresses the issue of bioavailability and the potential for contaminants to bioaccumulate. In this study, bioavailability was determined by examining the types and distributions of contaminants that bioaccumulated in laboratory studies (Rogerson, Schimmel, and Hoffman 1985). Based upon the contaminant profile for the dredged material and residue data, the contaminants selected for detailed analyses throughout the study included PCBs, PAHs, the pesticide ethylan, and eight metals.

73. A representative subset of chemicals was selected for discussion throughout the study. The criteria used in selecting this subset included chemical properties, contaminant representativeness and behavior in various compartments, and statistical analyses of the distributions of the complete suite of chemicals analyzed in the program.

74. Multivariate clustering analyses were performed on the chemical data in an attempt to define groups or clusters of chemicals that behaved in a statistically similar manner. No assumptions were made concerning the behavior, interactions, or dynamics of chemicals between compartments; therefore,

each compartment was analyzed separately. Five compartments were identified from field and laboratory data for statistical analysis. Of these, the surficial sediments and the unfiltered, particulate, and dissolved water column fractions described exposure conditions experienced by infaunal and pelagic organisms. The remaining compartment consisted of tissue residues in organisms.

75. The data were further partitioned into inorganic and organic analyses. The inorganic analyses generally consisted of 8 variables, whereas the organic analyses contained 61 variables. The clusters of chemicals identified through the statistical analyses agreed well with those contaminants selected, based on chemical properties and environmental behavior.

Statistical Analysis

76. The primary objective of the FVP was to compare laboratory with field responses under similar exposure conditions. Presented as an hypothesis, the quantitative exposure-response relationship derived from the laboratory studies would not be expected to differ significantly from a similar relationship developed from the field. The assumption implicit in this hypothesis is that the exposure conditions in the laboratory and field are analogous and can be defined in the same terms and to the same level of resolution. Because of the highly dynamic temporal and spatial conditions in the field, the exposure environment can be given only boundaries and cannot be assigned specific values, as is the case for laboratory studies. Consequently, the degree to which laboratory exposure-response relationships concur with those derived from field data can be described only qualitatively. That does not preclude the use of inferential statistical procedures to explore those laboratory and field relationships for which the appropriate quantitative information is available. The nature of this project was such that descriptive and exploratory statistics were often the most appropriate techniques to illustrate relations and trends. Simple graphic representations of variables were all that were necessary to illustrate a relationship. In addition, multivariate techniques, such as cluster analysis, were the most appropriate techniques to elucidate more complex relationships between groups of selected variables.

77. Prior to making comparisons between laboratory and field effects, it was necessary to establish whether field exposure boundaries were similar to those measured in the laboratory. Assuming that tissue residue and exposure are closely related, this was accomplished by examining the tissue residues of all worms from laboratory and field exposures together, independent of exposure concentration or station location and date. An agglomerative hierarchical cluster analysis was performed on the 10 selected chemical contaminants and the 2 summary statistics, using the Statistical Analysis System (SAS) cluster procedure (SAS 1985) to establish which tissue residues among all the laboratory treatments and field stations were most similar. The clustering procedure used was the average linkage method that uses unweighted pair-groups with arithmetic averages on squared distances between samples. Prior to analysis, residue data were normalized using standard deviations from the mean. This procedure ensured that each variable was weighted equally, even if its absolute value was orders of magnitude different from another variable.

78. The relationship between bioenergetic and tissue residue values was determined by regressing the values for the endpoints against the corresponding mean tissue residue (Snedecor and Cochran 1980). This procedure was completed individually for each of the 10 selected chemical contaminants and the 2 summary statistics.

PART III: RESULTS

Laboratory

Exposure

79. *Mytilus edulis* system monitoring. The *M. edulis* exposure system was monitored for both total suspended solid (TSS) concentrations and the percentage of REF and BRH sediments. The strip chart record indicated that the system maintained a suspended particulate concentration of 10 mg/ℓ approximately 90 percent of the time. Examples of times when the 10 mg/ℓ was not maintained include periods when exposure tanks were cleaned, slurry reservoirs were changed, and lines were clogged. Overall, the system provided a nearly constant total suspended particulate concentration to the mussels. The concentration of BRH sediments dosed into each treatment is listed in Table 5.

Table 5
Suspended Sediment Concentrations in the Mussel Exposure System

Nominal Percent BRH	Measured Percent BRH (S.E.)*	Calculated BRH Sediment mg/ℓ
100	100 (0.0)	10.0
50	50 (0.83)	5.0
30	33 (0.84)	3.3
10	15 (1.39)	1.5
0	0 (0.0)	0.0

* Standard error (S.E.) in parentheses.

80. When the TSS concentration dropped in the 50-percent BRH exposure tank, a pulse of equal length was sent to both the REF and BRH dosing valves. Volumetric measurements of the BRH and REF sediment doses indicated that equal amounts (± 5 percent) of BRH and REF material were delivered to the 50-percent BRH exposure chamber. The 100-percent BRH and 0-percent BRH treatments were controlled by single dosing values.

81. The 10- and 30-percent BRH treatments required two dosing valves per treatment. Because the pulse length could not be adjusted separately for each valve, manual adjustment of each valve was required to provide the

desired concentration. The volumetric amount of BRH and REF material delivered to each treatment was monitored and recorded. In the treatment with a nominal 10-percent BRH, the actual value delivered was 15 percent. In the 30-percent BRH treatment, the actual value was 33-percent BRH.

82. Mytilus edulis chemical monitoring. The results of the chemical monitoring are prefaced by a brief restatement of the purpose of the exposure system to aid in the understanding of the results. The system used in this experiment was designed to maintain a constant particulate concentration of 10 mg/l in the exposure chambers. Initially, 150 animals were placed into each chamber with clearance rates of approximately 2 l/mussel/hr, or a total of 300 l/hr. The seawater flow rate through each chamber, independent of suspended sediment additions, was approximately 24 l/hr. In effect, suspended sediment was added at a rate 12.5 times that of seawater to each exposure chamber each hour to compensate for sediment removed by the mussels. This has important consequences on the behavior of the contaminants in the exposure system.

83. If all the contaminants were associated with the suspended sediment, the contaminant concentrations in the exposure chambers should be similar to those predicted by regressing the TSS concentrations with contaminant concentrations in the BRH material. Conversely, any contaminants that do not remain bound to the particulates could attain concentrations in the exposure system different from those predicted from the TSS data. This occurs because the mussels in the system are more efficient at removing the particulate-bound contaminants than they are at removing the dissolved contaminants. This theory is proposed to explain the measured chemical concentrations in the exposure system, using PCB and copper as examples.

84. Whole water samples were taken for chemical analysis on Days 1, 7, 14, 21, and 28 in the second experiment. The mean PCB concentrations (nanogram per litre) for the five sampling dates for each exposure treatment in the second experiment are given in Table 6. The corresponding concentration of BRH sediment was estimated by regressing the nominal concentration of BRH against the expected value of PCB. Expected PCB concentrations were based on the PCB concentrations in the BRH sediment (6 ng/mg) plus background seawater concentrations. Substitution of the actual measured values of PCBs in the exposure system into the equation provided an estimated value of the concentration of BRH sediment in the system. The estimated concentration of BRH

Table 6
Chemical Monitoring of the *M. edulis* Exposure System in Experiment 2

Nominal Treatment Concentration, % BRH	PCB Concentration, ng/l		BRH Concentration, mg/l	
	Expected	Measured	Estimated	Measured
0	1.1	2.2	0.2	0
10	7.1	11.9	1.8	1.5
30	18.8	23.6	3.8	3.3

sediment in each treatment is similar to the actual measured values. These data suggest that PCB concentrations in the system are closely associated with the TSS concentrations.

85. Cu concentrations were measured both with and without mussels in the exposure system at 10 mg/l TSS for each treatment. With no mussels in the exposure system, the total Cu concentrations were 9.4 and 2.5 $\mu\text{g/l}$ for the 30-percent BRH and 10-percent BRH treatments, respectively. These concentrations represent 3.8 and 1.8 mg/l BRH sediment in the two treatments, respectively. Under these conditions, the predicted and measured Cu concentrations were comparable. This resulted because the effective flow of suspended sediment and incoming seawater is the same. The only loss of TSS was out the overflow due to seawater flow rates.

86. When mussels were present in the system, the mean Cu concentrations were 17.0 and 10.7 $\mu\text{g/l}$ for the 30-percent and 10-percent BRH treatments, respectively. These Cu concentrations correspond to 68- and 43-percent BRH sediment in the two treatments, respectively, and conflict with those expected from the TSS data. The results may be explained by the fact that Cu, because of its solubility in seawater, became disassociated from the TSS. Because suspended solids were delivered at a higher rate to the exposure chamber than the rate of incoming seawater, soluble Cu accumulated in the exposure chamber. When a dose of BRH suspended sediment was delivered to an exposure chamber, all contaminants were introduced at the same rate. Because the mussels were more efficient at removing particulates than dissolved contaminants, dissolved Cu tended to accumulate because its removal from the system was primarily via the overflow at a much slower rate. This resulted in higher concentrations of Cu than those predicted from the TSS data alone.

87. Nephtys incisa system monitoring. During the two *N. incisa* laboratory experiments, the exposure system was monitored for total suspended solids, temperature, and salinity. These data are presented in Table 7. In

Table 7
Measured Suspended Particulate Concentrations (Dry Weight) and Exposure
Conditions for Laboratory Test with *N. incisa*

Treatment % BRH	Concentration (mg/l) Suspended Particles $\bar{x} \pm SD$	Seawater Temperature $\bar{x} \pm SD$	Seawater Salinity (g/kg) $\bar{x} \pm SD$
<u>Test 1 - 12 Mar 1985 (28 days)</u>			
100	183 \pm 24	18.9 \pm 0.43	31.1 \pm 0.86
50	185 \pm 21	18.9 \pm 0.43	31.1 \pm 0.86
0	203 \pm 24	18.9 \pm 0.43	31.1 \pm 0.86
<u>Test 2 - 3 May 1985 (42 days)</u>			
100	201 \pm 23	19.8 \pm 0.53	30.9 \pm 0.70
50	184 \pm 19	19.8 \pm 0.53	30.9 \pm 0.70
0	190 \pm 21	19.8 \pm 0.53	30.9 \pm 0.70

general, the exposure system maintained the suspended solids concentrations close to the nominal 200 mg/l. Temperature and salinity values were stable at approximately 20° C and 30 g/kg, respectively. DO concentrations were checked once during each experiment, and they never differed significantly from expected saturation.

88. Nephtys incisa chemical monitoring. During the 42-day experiment, seawater and *N. incisa* from the exposure chambers were sampled for chemical analysis. Seawater chemical monitoring data are presented in Table 8. The dosing system malfunctioned for two days, spilling BRH sediments into all treatments. The Day 18 chemistry samples were taken during this period. The problem was corrected, and for the remainder of the test, the system performed normally. The chemistry data confirm that *N. incisa* received a graded exposure to BRH sediments.

Tissue residue

89. Mytilus edulis. Differences in contaminant concentrations between BRH and REF sediments facilitated the tracking of these contaminants in exposed biota (Appendix C). Results of Experiment 1 indicate that PCB tissue

Table 8
Chemical Analysis of Seawater in Exposure Chambers of 42-Day Experiment
Exposing *N. incisa* to BRH Sediment

Experiment Day	Treatment % BRH	Total PCB ng/l as Al254	Total Metals µg/l		
			Cu	Cd	Cr
3	100	NS*	407	5.4	245
	50		256	3.2	159
	0		15	0.1	15
6	100	1,170		NS	
	50	590			
	0	79			
18**	100	340	307	3.6	181
	50	510	208	3.5	125
	0	700	134	2.2	89
32	100	NS	357	5.0	203
	50		171	2.6	106
	0		15	0.1	16
42	100	1,920		NS	
	50	980			
	0	12			

* Not sampled.

** Dosing system malfunctioned for two days, spilling BRH sediments into all treatments.

concentrations in mussels are directly related to exposure concentrations (Table 9). PCBs in mussels from the 0-percent BRH concentration remained about the same over the 14-day experiment.

90. The PCB residue data from Experiment 2 are listed in Table 10 and graphically depicted in Figure 8. Tissue residues, measured at 7-day

Table 9
PCB Tissues Residues (ng/g Dry Weight) in Mussels from
Laboratory Experiment 1

Day	Percent BRH		
	0	50	100
0	117	117	117
14	154	2,100	3,700

Table 10
PCB Tissue Residues (ng/g Dry Weight) in Mussels from
Laboratory Experiment 2

Day	Percent BRH		
	0	10	30
0	210	210	210
7	280	1,110	2,100
14	270	1,910	3,600
21	360	1,720	3,600
28	280	1,840	3,700

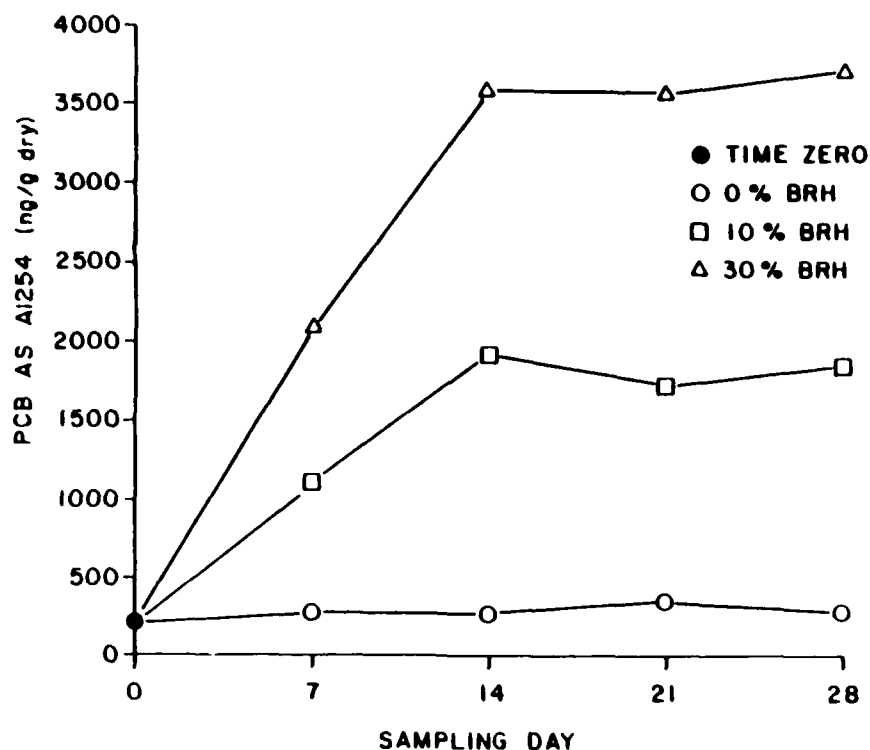


Figure 8. Concentrations of PCB as A1254 in the tissue of *M. edulis* exposed to BRH suspended sediments for 28 days

intervals, indicated that the mussels in the 0-percent BRH chamber maintained a relatively constant background concentration of PCBs throughout the experiment. In the 10- and 30-percent BRH chambers, the concentrations of PCBs in the mussels increased from Days 0 to 14, then remained nearly constant between Days 14 and 28, suggesting that the mussels reached a steady-state somewhere between Days 7 and 14. The steady-state PCB concentration in mussels in the

30-percent BRH treatment was almost double that of mussels from the 10-percent BRH treatment. The actual concentration of BRH dosed to the 30-percent BRH treatment, 3.3 mg/l, is nearly double that dosed to the 10-percent BRH treatment, 1.5 mg/l. The measured whole water concentrations of PCB were 11.86 and 23.57 ng/l for the 10- and 30-percent BRH treatments, respectively. These data indicate a good relationship between the actual dosed concentrations of BRH suspended sediment, the measured whole water concentrations, and the PCB tissue residues in the mussels in Experiment 2.

91. A comparison of the tissue residues between the two experiments can be made for Days 0 and 14. The PCB concentration in the Day 0 mussels from Experiment 1 was almost half that in those from Experiment 2 (117 and 210 ng/g, respectively). In addition, Day 14 PCB concentrations were about the same for the 10- and 50-percent BRH exposed mussels (1,910 and 2,100 ng/g) as well as the 30- and 100-percent BRH exposed mussels (3,600 and 3,700 ng/g). These data show dose responses within each experiment; however, agreement between experiments is poor. PCB data from these experiments were normalized to nanograms/gram of lipid, and the results are presented in Table 11 and Figure 9. Inspection of these data shows that differences between experiments can be explained when differences in lipid content of the organisms are taken into account. In addition, this procedure indicates that a dose-response relationship does exist between experiments when the Day 14 data from both experiments are combined (Figure 9).

Table 11
PCB Concentrations (ng/g Lipid) in Mussels
from Both Laboratory Experiments

Day	Percent BRH Treatments					
	0	0	10	30	50	100
0	2,900	2,400	2,400	2,400	2,900	2,900
7	--	5,200	17,100	24,000	--	--
14	3,800	4,300	27,000	54,000	53,000	119,000
21	--	5,000	35,000	67,000	--	--
28	--	3,800	30,000	66,000	--	--

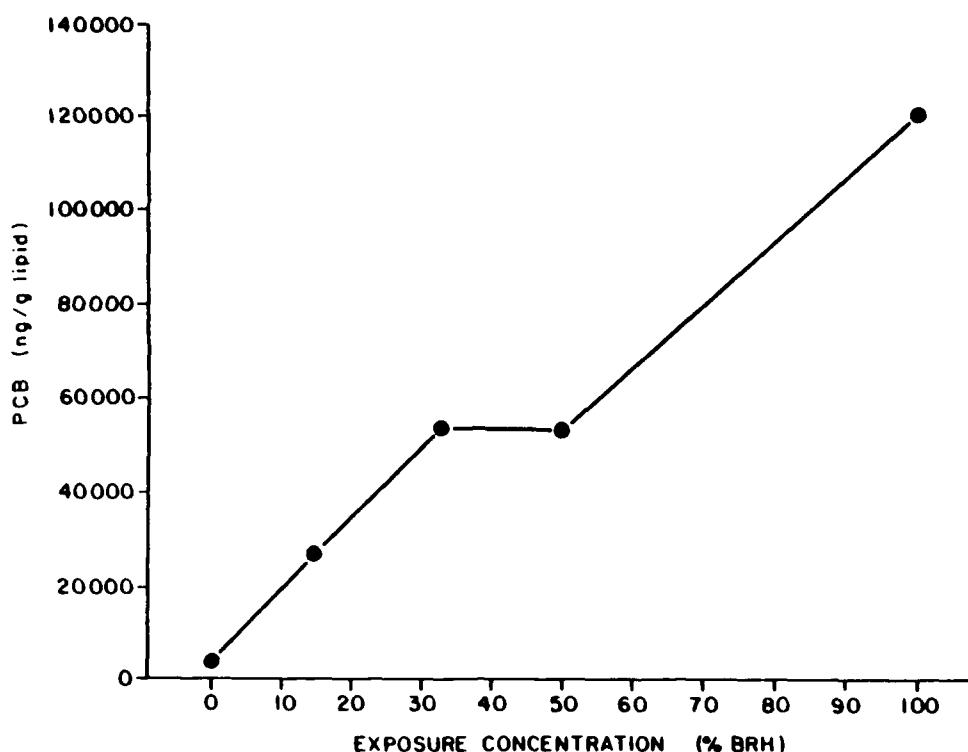
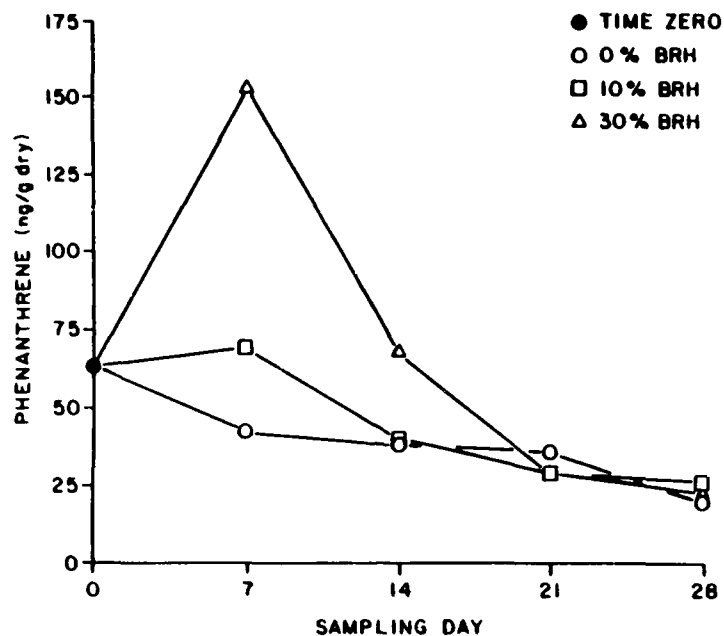


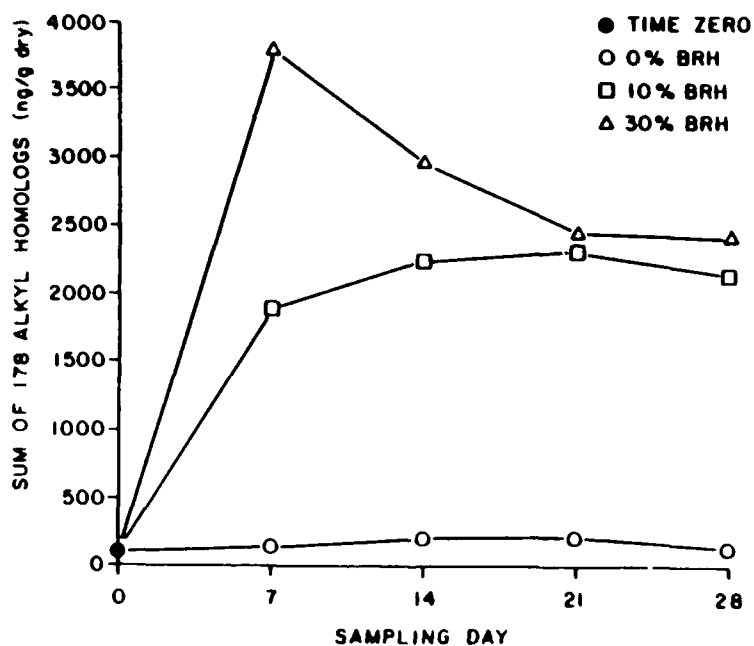
Figure 9. Concentrations of PCB as A1254, normalized for lipids, in the tissue of *M. edulis* exposed to BRH sediment for 14 days

92. In addition to PCBs, tissue residues of phenanthrene, the sum of the 178 alkyl homologs, fluoranthene, benzo(a)pyrene, ethylan, cadmium, copper, chromium, and iron were also measured on Days 0, 7, 14, 21, and 28 of Experiment 2. The summary statistics, SUM and CENT, of the PAHs were also calculated for each of these sampling dates. These data are summarized graphically in Figures 10-15.

93. While each of the graphs presented in Figures 10-15 will not be discussed at length, it is interesting to note the relationship between the molecular weight of the organic compounds and tissue residue over time. The benzo(a)pyrene tissue residues follow a pattern similar to that of PCB. After 7 days, residues remain nearly constant for each exposure concentration. The fluoranthene residues are initially higher in the 30-percent BRH treatment. However, they decrease over the 28-day exposure period to a level comparable with the 10-percent BRH treatment. Mussel residues for both of these treatments are elevated compared with the 0-percent BRH treatments. Phenanthrene, an even lower molecular weight PAH, increased initially but then decreased in both the 30- and 10-percent BRH treatments to a level comparable with the

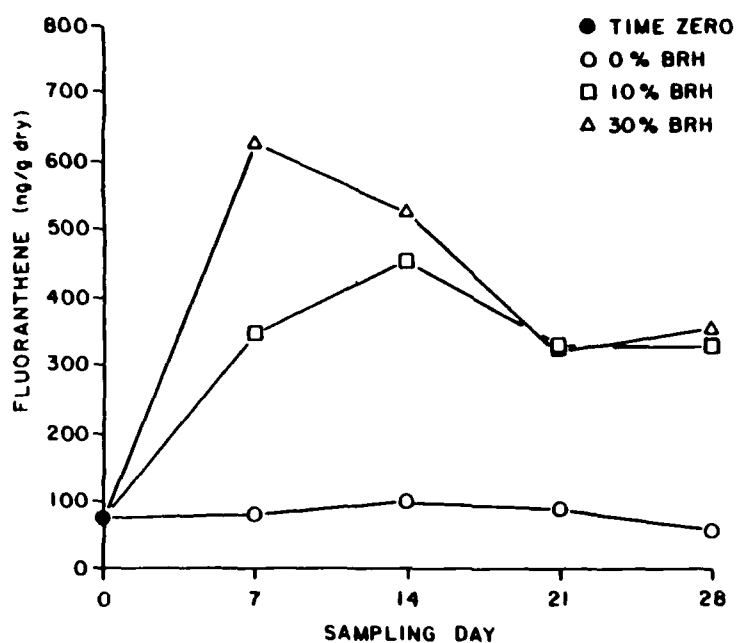


a. Phenanthrene

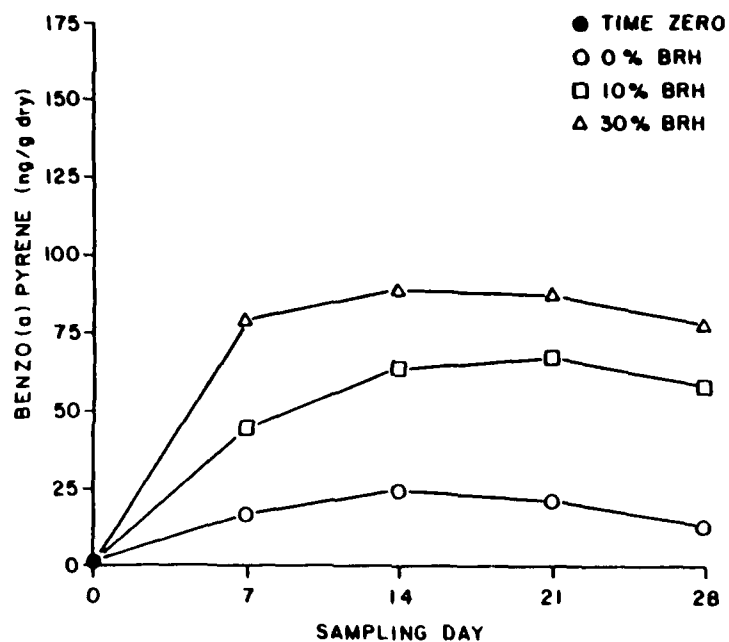


b. 178 alkyl homologs

Figure 10. Concentrations of phenanthrene and 178 alkyl homologs in the tissue of *M. edulis* exposed to BRH suspended sediments for 28 days

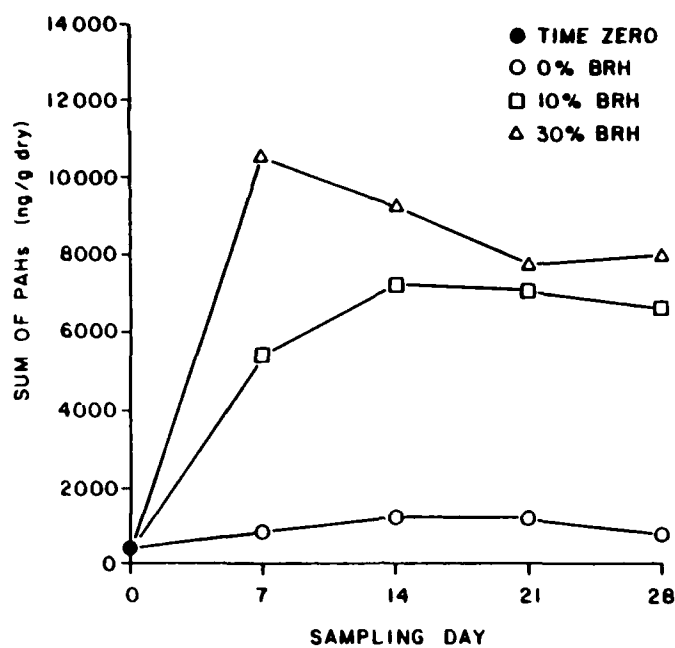


a. Fluoranthene

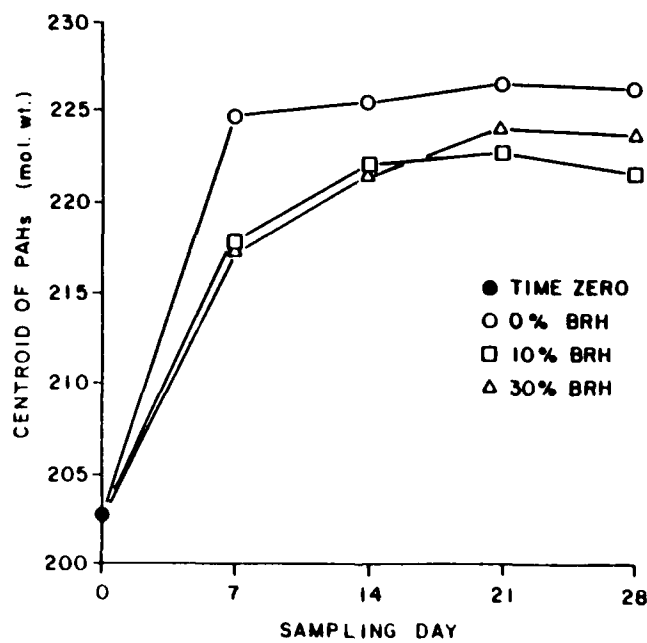


b. Benzo(a)pyrene

Figure 11. Concentrations of fluoranthene and benzo(a)pyrene in the tissue of *M. edulis* exposed to BRH suspended sediments for 28 days

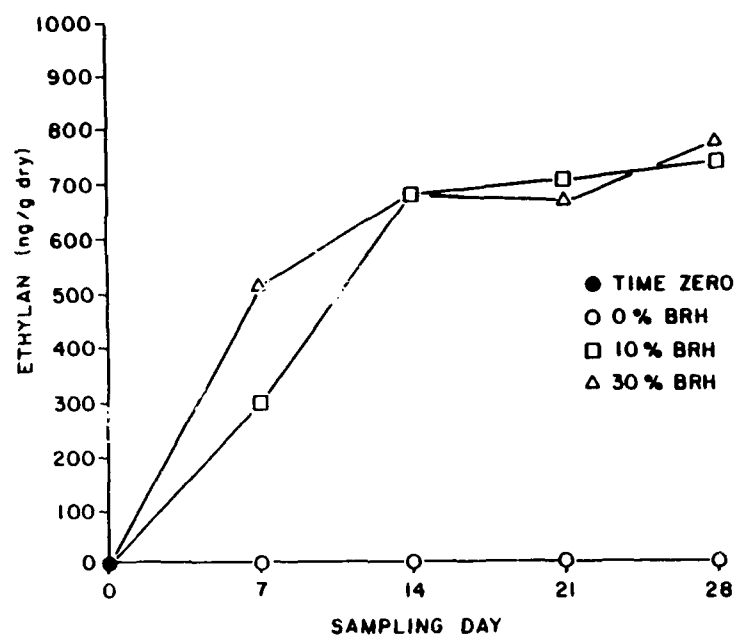


a. SUM of PAHs

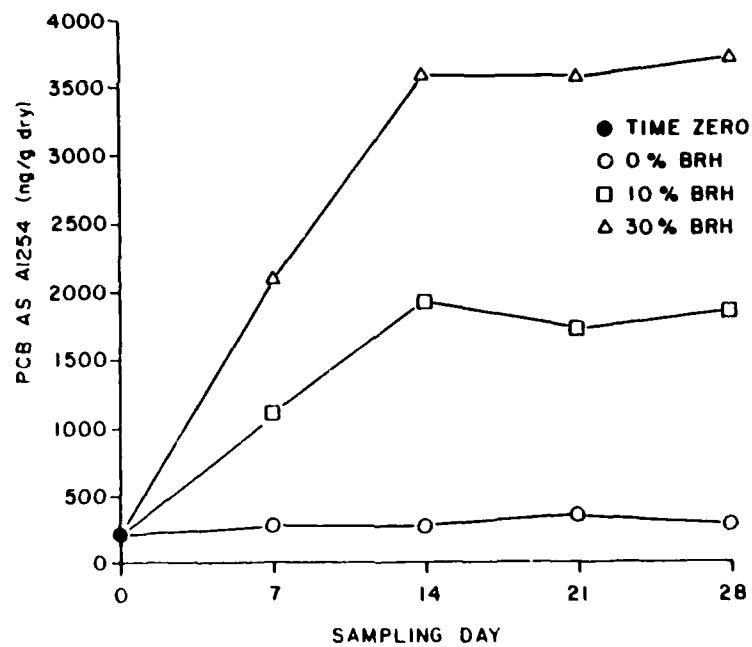


b. CENT of PAHs

Figure 12. Concentrations of the SUM of PAHs and CENT of PAHs in the tissue of *M. edulis* exposed to BRH suspended sediments for 28 days

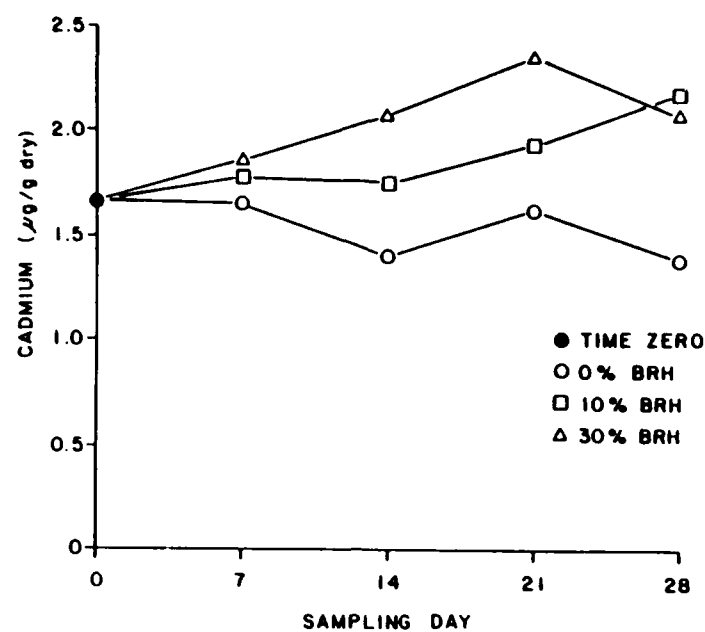


a. Ethylan

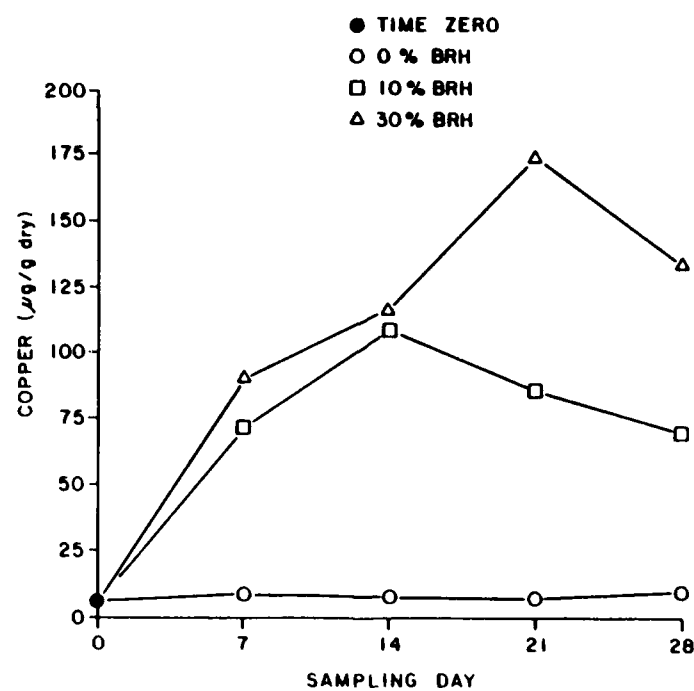


b. PCB

Figure 13. Concentrations of ethylan and PCB as A1254 in the tissue of *M. edulis* exposed to BRH suspended sediments for 28 days

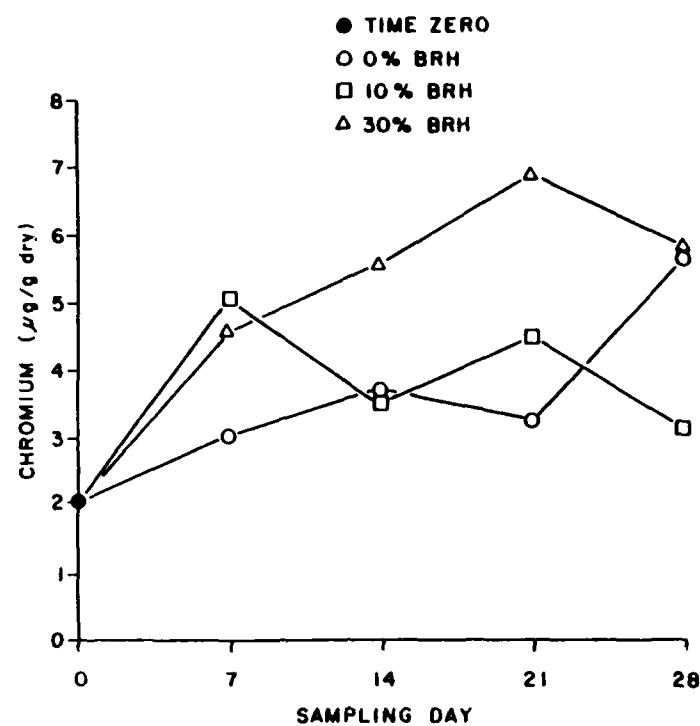


a. Cadmium

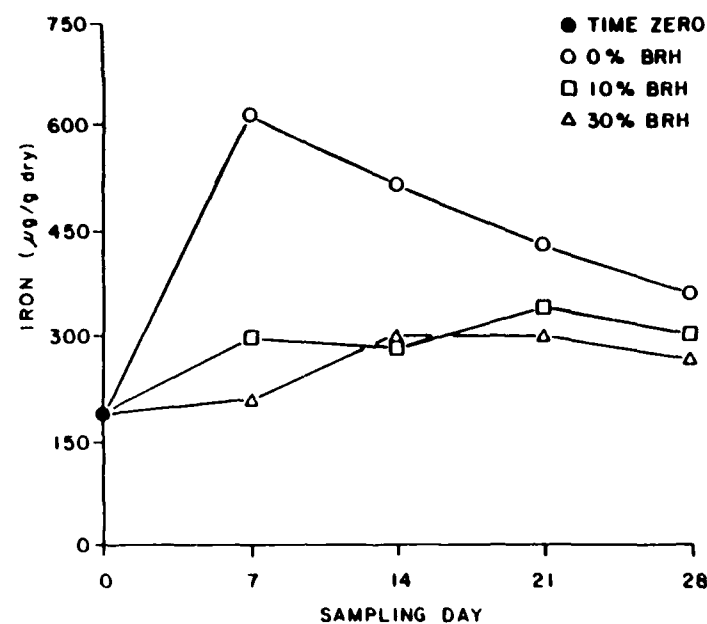


b. Copper

Figure 14. Concentrations of cadmium and copper in the tissue of *M. edulis* exposed to BRH suspended sediments for 28 days



a. Chromium



b. Iron

Figure 15. Concentrations of chromium and iron in the tissue of *M. edulis* exposed to BRH suspended sediments for 28 days

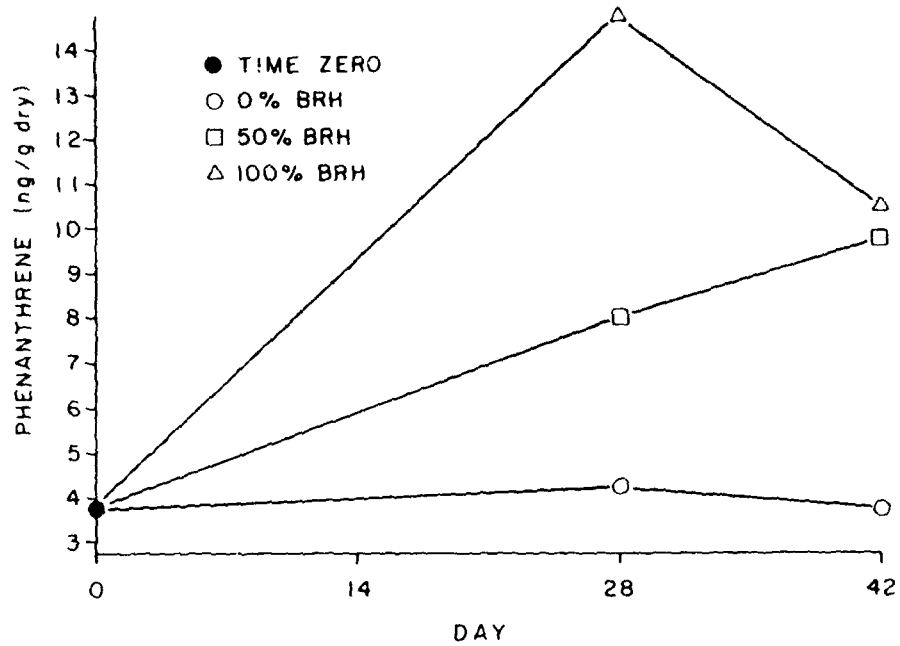
0-percent BRH exposure. These data would suggest that mussels have the ability to metabolize and/or excrete the lower molecular weight PAHs, even during continuous exposure. In addition, the data would indicate that only higher molecular weight compounds should be used to relate exposure levels and subsequent tissue residue levels, because even under relatively constant exposure conditions, residues of lower molecular weight PAHs did not reflect exposure concentrations.

94. Nephtys incisa. *Nephtys incisa* tissues from suspended sediment laboratory exposures were analyzed for phenanthrene, the sum of the 178 alkyl homologs, fluoranthene, benzo(a)pyrene, ethylan, copper, cadmium, chromium, and iron. These tissue residues were measured on samples from Days 0, 28, and 42 of the experiment. The summary statistics, SUM and CENT, of the PAHs were also calculated for each of these sampling dates. These data are presented graphically in Figures 16-21.

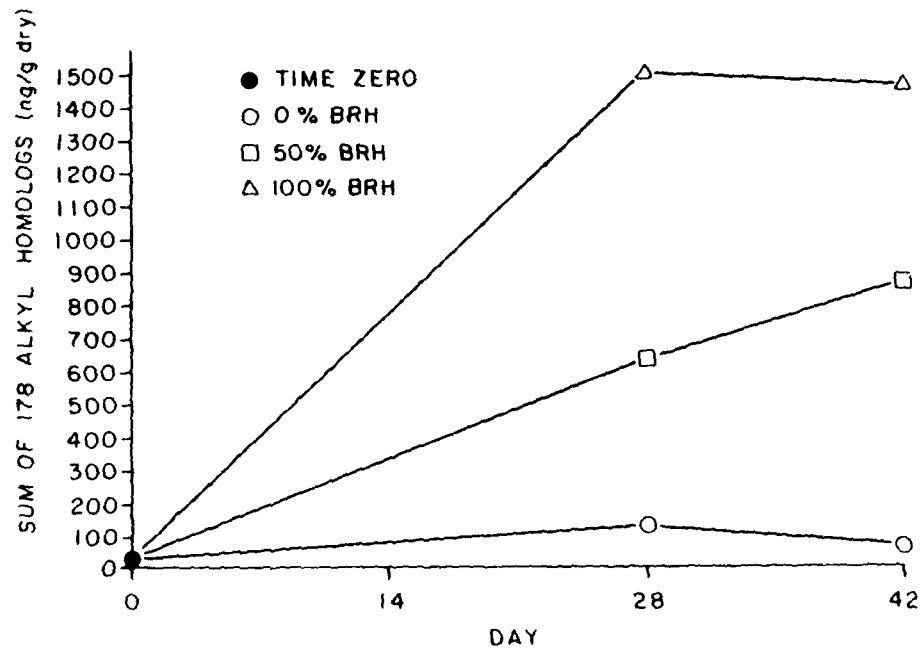
95. Although these data are not discussed in detail (see Lake, Hoffman, and Schimmel 1985), some general observations are made. The tissue residue concentrations of all the organic compounds increased with increasing exposure. The PAHs, with the exception of fluoranthene, reached their highest measured tissue concentrations at Day 28 and exposure concentrations of 200-mg BRH/l (100-percent BRH). The residue concentrations for phenanthrene and benzo(a)pyrene declined by 30 percent and 50 percent, respectively, by Day 42. The tissue residue concentration of PCBs reached an apparent steady-state at the 100-mg BRH/l (50-percent BRH) exposure by Day 28, although there was a continued increase at 200 mg/l (100-percent BRH) at Day 42. As the result of its kinetic, partitioning, and persistence properties, PCB was selected as a "tracer" for BRH material and used to relate BRH exposure conditions to tissue residues. Not all the inorganic compounds produced increased tissue concentrations. Copper and cadmium, which have soluble fractions in seawater, did produce elevated tissue concentrations as a consequence of increased exposure to BRH suspended sediment (Figure 20). Chromium and iron, which are bound to particulates, did not produce elevated tissue concentrations and, in fact, showed apparent depuration of these compounds from Days 28 to 42.

Histopathological effects

96. Mytilus edulis. The histopathological results for *Mytilus edulis* exposed in the laboratory to BRH sediments are presented in Tables 12 and 13. In the first experiment, histopathological changes were noted in the

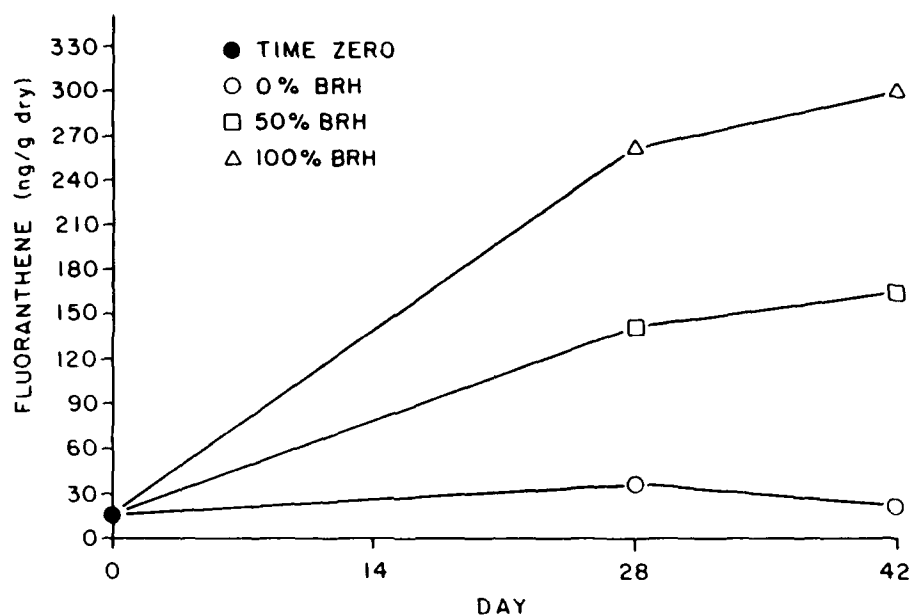


a. Phenanthrene

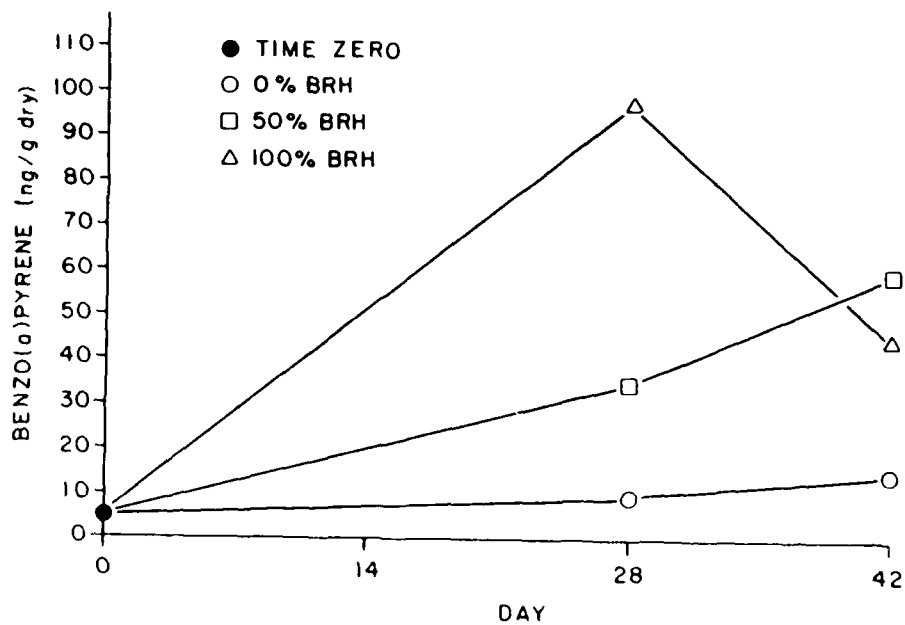


b. 178 alkyl homologs

Figure 16. Concentrations of phenanthrene and 178 alkyl homologs in the tissue of *N. fouisa* exposed to BRH suspended sediments for 42 days

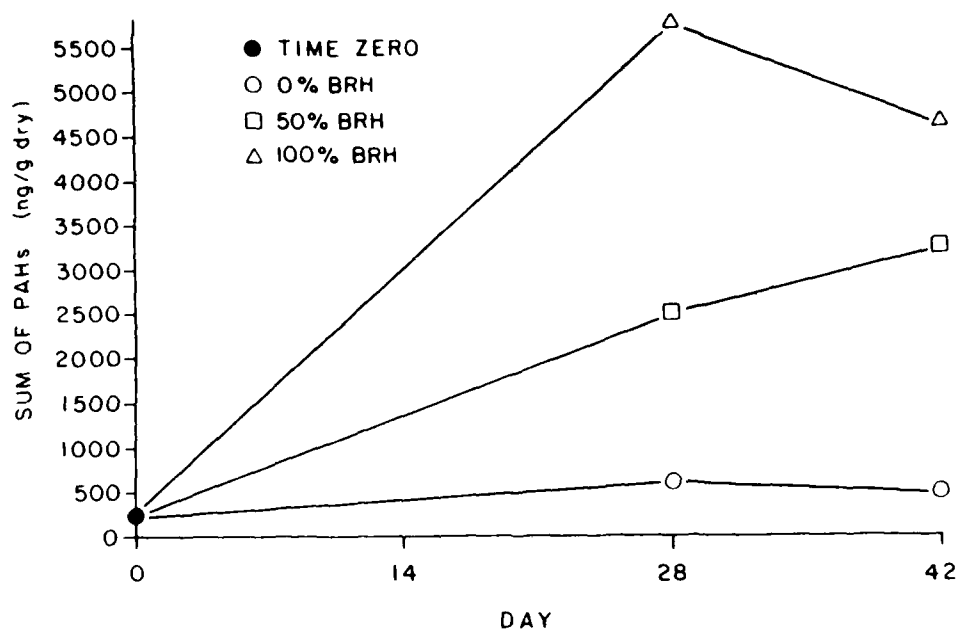


a. Fluoranthene

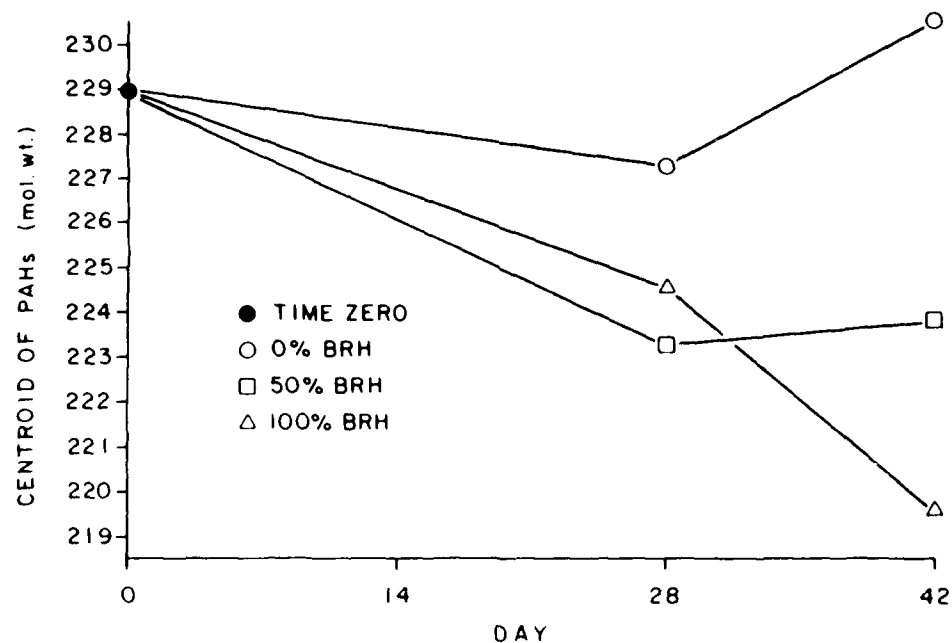


b. Benzo(a)pyrene

Figure 17. Concentrations of fluoranthene and benzo(a)pyrene in the tissue of *N. incisa* exposed to BRH suspended sediments for 42 days

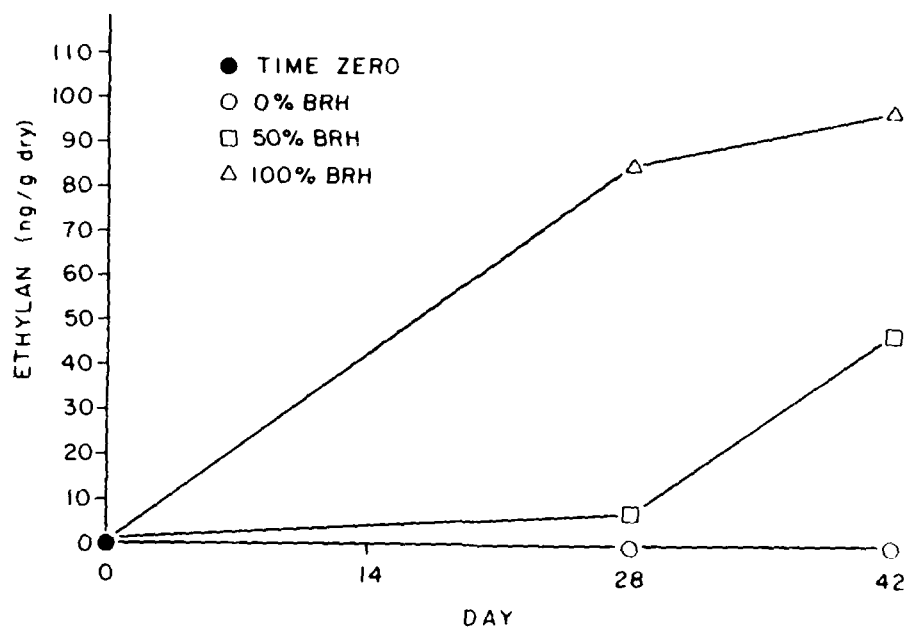


a. SUM of PAHs

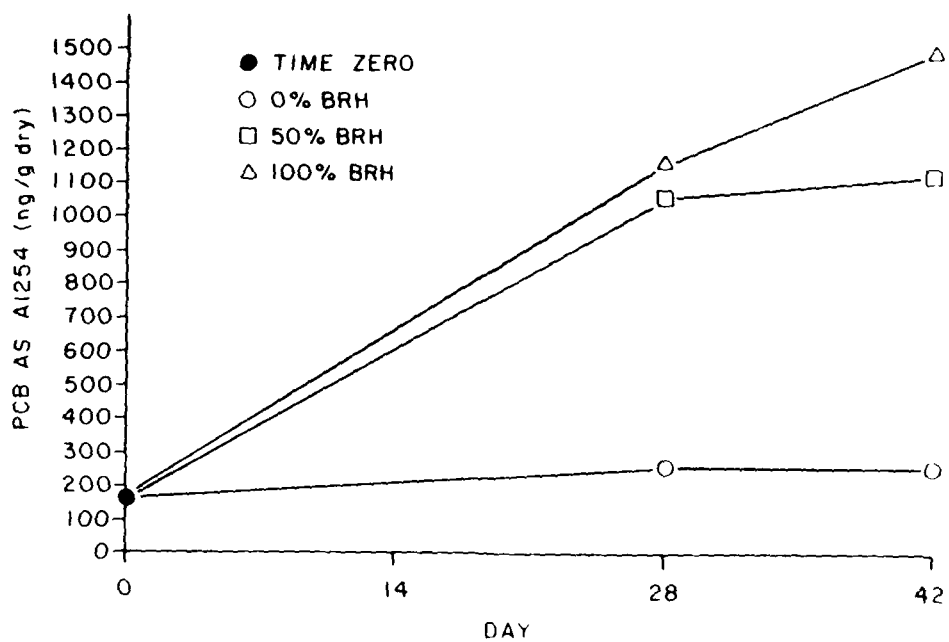


a. CENT of PAHs

Figure 18. Concentrations of the SUM of PAHs and CENT of PAHs in the tissue of *N. incisa* exposed to BRH suspended sediments for 42 days

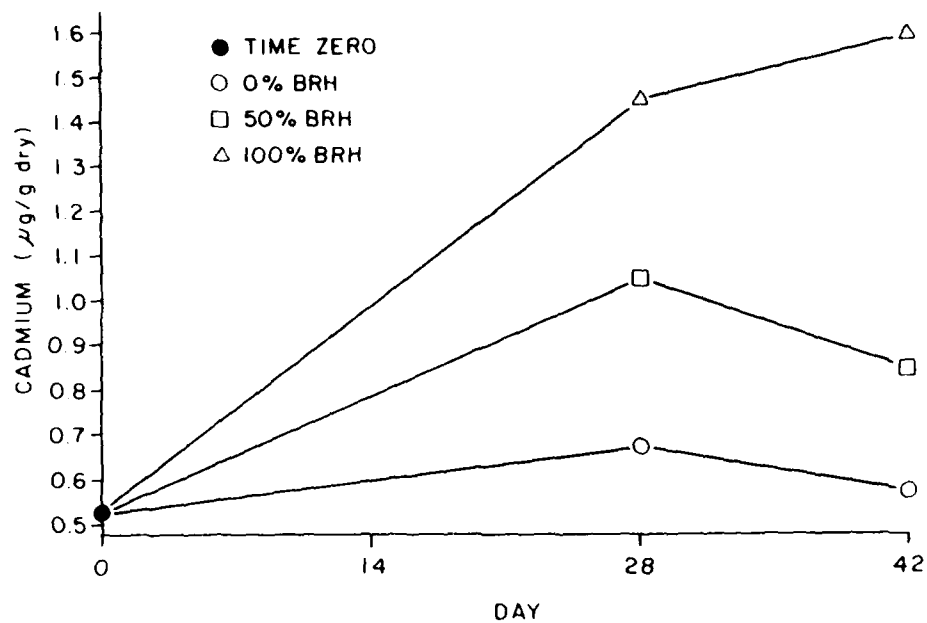


a. Ethylan

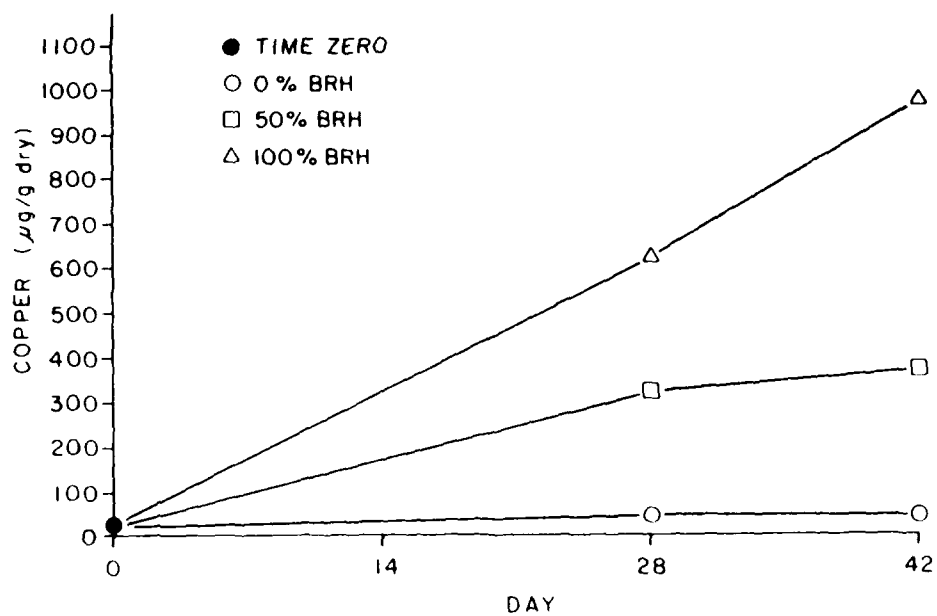


b. PCB

Figure 19. Concentrations of ethylan and PCB as Al254 in the tissue of *M. balthica* exposed to BRH suspended sediments for 42 days

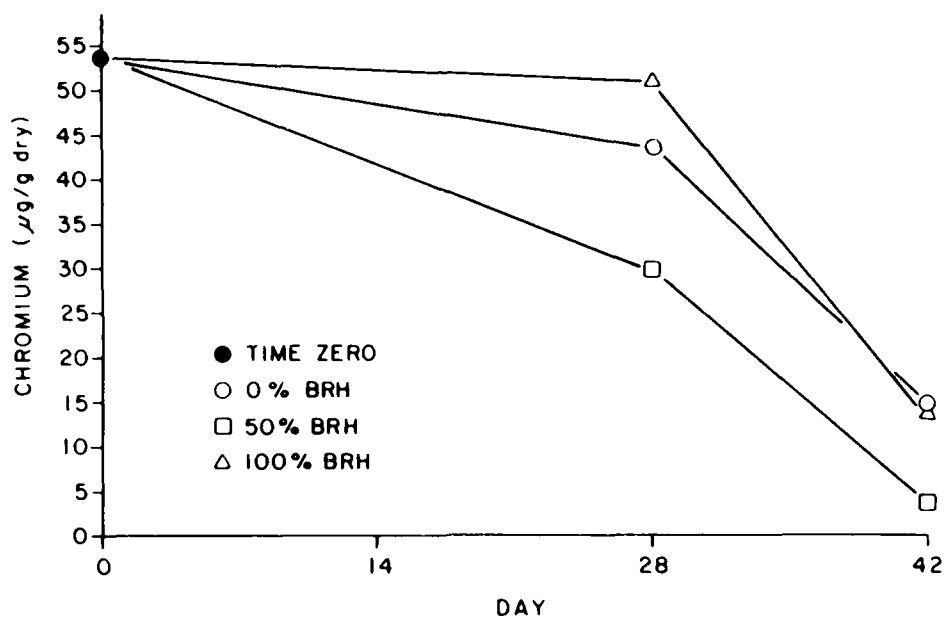


a. Cadmium

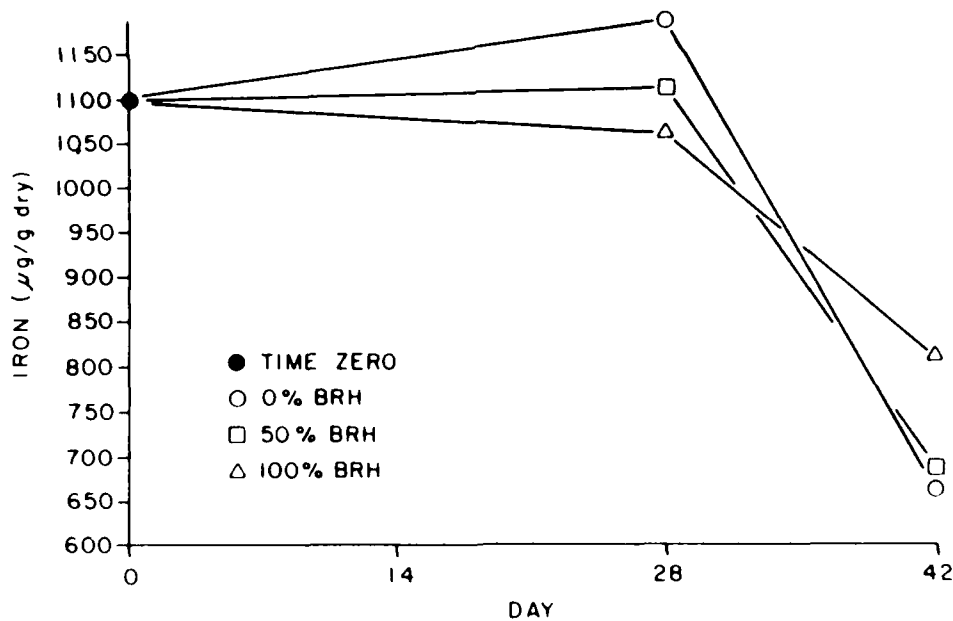


b. Copper

Figure 20. Concentrations of cadmium and copper in the tissue of *M. lineatus* exposed to BRH suspended sediments for 42 days



a. Chromium



b. Iron

Figure 21. Concentrations of chromium and iron in the tissue of *N. incisa* exposed to BRH suspended sediments for 42 days

reproductive tract, gills, kidney, gastrointestinal tract, muscle, and byssus organ of the 100-percent BRH exposed group and in the gills and the gastrointestinal tract of mussels in the 50-percent REF/50-percent BRH group (Table 12).

Table 12
Histopathological Findings for *M. edulis* Exposed to Suspended Particles
of BRH Material for 14 Days in the Laboratory

Organs Examined	Exposures							
	Preexposure Control		100% REF		50% REF/ 50% BRH		100% BRH	
	N*	%**	N*	%**	N*	%**	N*	%**
Reproductive tract								
Males	11	0	13	0	7	0	12	0
Females	6	0	4	0	10	0	6	5
Undifferentiated	3	0	3	0	3	0	2	50
Heart	20	0	20	0	20	0	20	0
Gills	20	0	20	0	20	100	20	100
Kidney	20	0	20	0	20	0	20	25
GI tract†	20	0	20	0	20	50	20	65
Muscle	20	0	20	0	20	0	20	10
Byssus organ	20	0	20	0	20	0	20	10

* N = Number of animals examined.

** % = Percent of examined specimens showing histopathological changes.

† GI tract = Gastrointestinal tract.

97. In the 100-percent BRH group, three of the female mussels (50 percent) and one undifferentiated mussel (50 percent) showed pathology of the reproductive tract. One of the females had vacuolation of some of the small ova, and two had necrosis of the ova. The undifferentiated mussels exhibited necrosis of the germinal epithelium.

98. Most of the gill filaments of all of the mussels exposed to 100-percent BRH showed histopathological changes (Figures 22 and 23). The normally squamous epithelium had become cuboidal and had many vacuolated cells. There was extensive loss of frontal and lateral frontal cilia from the gills of four animals (20 percent), a moderate loss from five animals (25 percent), and a negligible loss in the remaining animals. In addition, four

Table 13

Histopathological Findings for *M. edulis* Exposed to Suspended Particles
of BRH Material for 28 Days in the Laboratory

Organs Examined	Exposures							
	Preexposure Control		100% REF		10% BRH		30% BRH	
	N*	%**	N*	%**	N*	%**	N*	%**
Reproductive tract								
Males	8	0	8	0	6	0	7	0
Females	6	0	5	0	8	0	5	20
Undifferentiated	1	0	2	0	1	0	3	0
Heart	15	0	15	0	15	0	15	0
Gills	15	0	15	0	15	80	15	80
Kidney	15	0	15	0	15	0	15	7
GI tract†	15	0	15	0	15	0	15	7
Muscle	15	0	15	0	15	0	15	0
Byssus gland	15	0	15	0	15	0	15	0

* N = Number of animals examined.

** % = Percent of examined specimens showing histopathological changes.

† GI tract = Gastrointestinal tract.

mussels exhibited extensive foci of atypical cell hyperplasia, while five showed a moderate amount, and eight had a light amount. Also, basophilia increased in some of the filaments.

99. The kidneys of five mussels (25 percent) from the 100-percent BRH treatment group showed some pathology. Kidneys of two specimens exhibited swelling and vacuolation of the kidney epithelial cells, while two others had foci of hyperplasia and an increase in basophilic cells in the tubular epithelium. One had necrosis and sloughing of epithelium of several tubules.

100. Thirteen mussels (65 percent) from the 100-percent BRH group had a variety of histopathological changes in the digestive diverticula of the gastrointestinal tract. Two mussels had extensive dilation of the tubules of the digestive diverticula, which produced a loss of digestive granules and a squamous epithelium. One mussel exhibited atrophy of digestive tubules, and six mussels showed destruction of some tubules. There was a large increase in the number of basophilic cells in the tubules of three mussels, a moderate



Figure 22. *Mytilus edulis*, gills from animal exposed to 0-percent BRH. Arrow points to the ciliated column epithelium of the gill filaments

increase in five mussels, and a slight increase in two mussels. Five animals had extensive loss of granules from the digestive cells, including two with squamous epithelium. Six animals exhibited swelling and vacuolation of the duct epithelium, and six had foci of hyperplasia of the duct epithelium. Two had moderately dilated ducts, and one had extensively dilated ducts. Three mussels showed some evidence of necrosis and sloughing of the duct epithelium, and one specimen exhibited a greater degree of necrosis. Three had destruction of several ducts. Two animals in this exposure group had a large amount of myodegeneration of the adductor and byssus muscles.

101. In the 50-percent BRH group, all animals had some gills with abnormal epithelium lining the filaments. The normally squamous epithelium became cuboidal, and a large number of these cells were vacuolated. Eleven animals had slight amounts of atypical cell hyperplasia, and two had a moderate amount along the filaments. There was a slight loss of cilia from the gills of six animals.

102. Ten of the mussels (50 percent) in this group had some histopathology of the digestive diverticula. However, the damage was not as extensive



Figure 23. *Mytilus edulis*, gills from animal exposed to 100-percent BRH. Arrows point to loss of cilia of the column epithelium. Arrow A points to a fusion of the gill epithelium

as seen in the 100-percent BRH group. It consisted of swelling and/or vacuolation of the duct epithelium in 10 individuals with a light amount of sloughing of the epithelium from the walls of the ducts in 6 mussels. Four of the animals from this group also exhibited an increase in basophilic cells lining the digestive tubules. All other cells and tissues from the mussels exposed to 50-percent BRH were within the histological conditions observed in the control group exposed to 100-percent REF.

103. In the second experiment (Table 13), which ran for 28 days, histopathological changes were noted in the reproductive tract, gills, kidney, and gastrointestinal tract of the mussels exposed to 30-percent BRH and in the gills but not the kidneys of individuals from the 10-percent BRH group. Overall, however, the histopathology of the mussels exposed in this experiment was not as extensive as was observed in the mussels analyzed from the first experiment (Table 12).

104. In the 30-percent BRH exposure group, one female (20 percent) had a few vacuolated small ova. One individual (7 percent) had a focus of

destruction of the kidney epithelium, and one animal (7 percent) exhibited an increase in basophilic cells of the digestive tubules. The gills of 12 of the mussels (80 percent) exhibited a moderate change from squamous to cuboidal epithelium along some of the filaments. Many of the cuboidal cells were vacuolated. Three individuals had a moderate amount of atypical cell hyperplasia, and four others had hyperplasia to a lesser degree. In addition to these abnormal histologies, two mussels exhibited foci of abnormal gill filaments, while one specimen had a small loss of frontal cilia from some of the gills.

105. The gills of individuals from the 10-percent BRH group exhibited similar types of histopathologies as those individuals exposed to the 30-percent BRH treatment. Twelve mussels (80 percent) had vacuolated cuboidal cells rather than the normal squamous epithelium along the filaments. One animal had a small loss of frontal cilia from the gills, and two others had a few abnormal gill filaments. All other cells and tissues examined in mussels from this exposure group were similar in appearance to the cells and tissues of the 0-percent BRH group.

106. Nephtys incisa. Few histological changes were observed in *Nephtys incisa* in laboratory exposures to suspended BRH material for 28 and 42 days. In the first laboratory study, lasting 28 days (Table 14), 40 percent of the worms from the 50-percent BRH group and 66 percent of the individuals from the 100-percent BRH group exhibited thickening of the epidermis.

107. The sites of thickening were characterized as having a darker skin color than surrounding tissue. Chitin and squamous epithelium in the affected area showed accumulation of brown to black particles. Macrophages containing black particles were noted around blood vessels in the parapodia and were also seen being extruded through the epidermis of the gills (Figure 24). The histology of worm epidermis from the 0-percent BRH treatment is presented in Figure 25. In general, the number of black particles and the amount of macrophage excretions observed were greater in the 100-percent BRH group than they were in the 50-percent BRH group.

108. Similar results were found for the 50-percent BRH and 100-percent BRH groups in the 42-day exposure, except that an increase in the amount of brown and black particles was noted in the epidermis (Table 15). In addition, the gills also exhibited an increase in macrophage excretion activity.

Table 14

Histopathological Findings for *N. incisa* Exposed to Suspended Particles
of BRH Material for 28 Days in the Laboratory

Organs Examined	Exposures					
	100% REF		50% BRH		100% BRH	
	N*	%**	N*	%**	N*	%**
Epidermis	6	0	5	40	6	66
Muscle	6	0	5	0	6	0
Intestine	6	0	5	0	6	0
Nervous system	6	0	5	0	6	0
Reproductive tract	6	0	5	0	6	0

* N = Number of specimens examined.

** % = Percent of examined specimens showing histopathological changes.

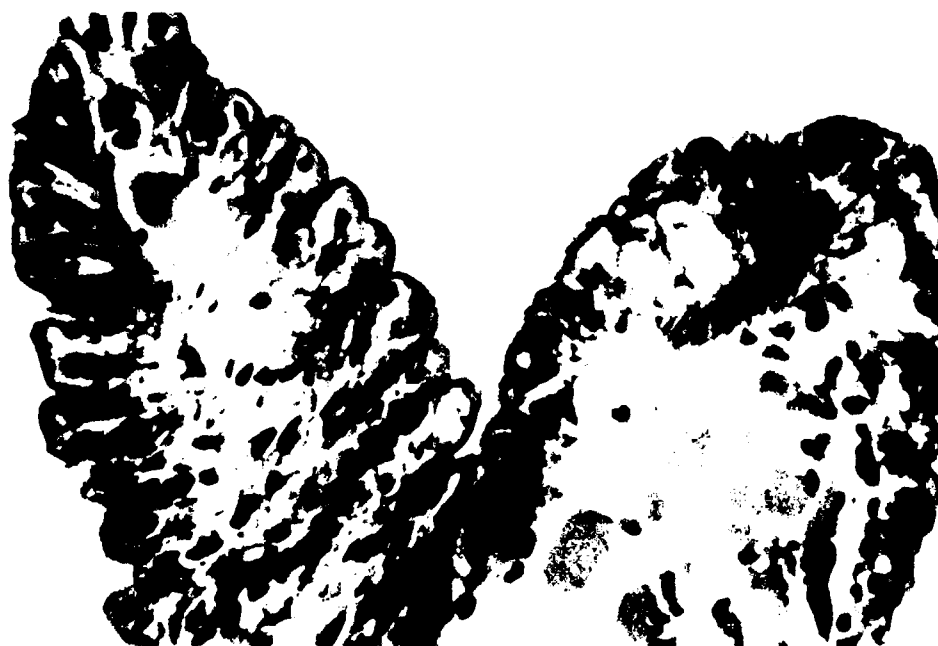


Figure 24. *Nephys incisa*, epidermis from animal exposed to 100-percent BRH sediment. Note thickening and darkening of epidermis and accumulation of particles



Figure 25. *Nephtys incisa*, epidermis from animal exposed to 0-percent BRH sediment

Table 15

Histopathological Findings for *N. incisa* Exposed to Suspended Particles
of BRH Material for 42 Days in the Laboratory

Organs Examined	Exposures					
	100% REF		50% BRH		100% BRH	
	N*	%**	N*	%**	N*	%**
Epidermis	11	0	11	18	5	100
Muscle	11	0	11	0	5	0
Intestine	11	0	11	0	5	0
Nervous system	11	0	11	0	5	0
Reproductive tract	11	0	11	0	5	0

* N = Number of specimens examined.

** % = Percent of examined specimens showing histopathological changes.

Field

Exposure

109. *Mytilus edulis* exposures estimated from tissue residues. The first method used to estimate exposure conditions of *M. edulis* to BRH material in CLIS involved the use of laboratory-generated relationships between PCB tissue residues and BRH exposures. Three assumptions are inherent in this process: (a) mussels provided an integrated measure of exposure during each field deployment, (b) mussels were at equilibrium with background BRH levels in the water column, and (c) PCBs are a good chemical marker for BRH material. Based on the results of the laboratory experiments, each of these assumptions seems reasonable.

110. The predicted exposures for each station and collection date demonstrate several spatial and temporal trends (Table 16). Spatially, the data indicate a trend towards greater exposure near the CNTR station immediately following disposal. This is evidenced by the elevated exposures at $T = 0$ ($1000E > REFS$) and $T + 2$ ($400E > 1000E > REFS$) toward the disposal mound. This pattern disappeared by $T + 8$, where exposures were nearly the same at the CNTR, 400E, and 1000E stations, with the REFS station being lower than the other three.

111. Temporarily, the estimated BRH exposures decreased with increasing time from disposal. The maximum exposure occurred at the 400E station at $T + 2$. This value ranged between 1.4 and 0.8 mg/l of BRH suspended sediment, depending on whether the background concentration at REFS was subtracted. By the next collection, $T + 8$, the maximum estimated exposure, also at 400E, decreased to between 0.7 and 0.3 mg/l, half that of the previous collection. Subsequent collections indicated a continued decrease to levels similar to those at the REFS station by $T + 12$.

112. Exposures estimated from water chemistry data. In addition to the estimates of BRH exposure based on mussel PCB tissue residues, a second estimate was made using PCB and Cu concentrations in whole water samples taken postdisposal. The data indicate spatial and temporal trends similar to those obtained from the tissue residue estimates (Table 17).

113. Spatially, the sample collected on 7 June 1983 showed the highest BRH estimate (based on Cu) at the CNTR station, followed by lower concentrations at 400E and 1000E stations, and the lowest levels at REFS. The estimate

Table 16

Predicted Range of BRH Suspended Sediment Exposures (mg/l)
Required to Achieve the Measured Tissue Residue Values
of Mussels Deployed in CLIS*

<u>Collection Cruise</u>	<u>Station</u>	<u>Estimated Exposure Range</u>	
		<u>High Value</u>	<u>Low Value</u>
T - 04	CNTR	0.37	0.00
	400E	0.26	0.00
	1000E	0.38	0.00
	REFS	0.43	0.00
T = 0	1000E	1.04	0.56
	REFS	0.49	
T + 2	400E	1.39	0.79
	1000E	0.98	0.38
	REFS	0.60	
T + 8	CNTR	0.67	0.21
	400E	0.71	0.25
	1000E	0.60	0.14
	REFS	0.46	
T + 12	CNTR	0.61	0.06
	400E	0.64	0.09
	1000E	0.53	0.00
	REFS	0.55	
T + 15	CNTR	0.84	0.31
	400E	0.61	0.08
	1000E	0.61	0.08
	REFS	0.53	
T + 21	CNTR	0.52	0.12
	400E	0.66	0.26
	1000E	0.55	0.15
	REFS	0.40	
T + 27	400E	0.52	0.09
	1000E	0.37	0.00
	REFS	0.43	

(Continued)

* Each estimate was calculated based on laboratory-generated PCB residue-exposure concentration relationships. The high value was determined from the actual mussel tissue residue concentration while the low estimate was calculated after the REFS PCB residue was subtracted from the other stations during that collection period.

Table 16 (Concluded)

<u>Collection Cruise</u>	<u>Station</u>	<u>Estimated Exposure Range</u>	
		<u>High Value</u>	<u>Low Value</u>
T + 43	CNTR	0.33	0.06
	400E	0.31	0.04
	REFS	0.27	
T + 55	400E	0.52	0.00
	1000E	0.42	0.00
	1000E	0.47	0.00
	REFS	0.53	
T + 116	CNTR	0.30	0.00
	400E	0.34	0.00
	1000E	0.43	0.01
	REFS	0.42	

Table 17
Predicted BRH Suspended Sediment Exposure (mg/l) Based on
PCB and Cu Whole Water Chemistry Data*

<u>Date</u>	<u>Station</u>	<u>Estimate Using Cu</u>		<u>Estimate Using PCB</u>	
		<u>High</u>	<u>Low</u>	<u>High</u>	<u>Low</u>
07 Jun 83	CNTR	1.30	0.71	1.05	0.69
	400E	1.12	0.53	--	--
	1000E	1.14	0.55	--	--
	REFS	0.59	0.00	0.36	0.00
21 Jul 83	CNTR	0.62	0.26	0.19	0.11
	400E	0.49	0.13	--	--
	1000E	0.41	0.05	--	--
	REFS	0.36	0.00	0.08	0.00
31 Aug 83	CNTR	--	--	0.17	0.07
	400E	--	--	0.21	0.11
	1000E	--	--	0.16	0.06
	REFS	--	--	0.10	0.00
02 Sep 83	CNTR	--	--	--	--
	400E	0.72	0.22	--	--
	1000E	--	--	--	--
	REFS	0.50	0.00	--	--
05 Dec 83	CNTR	--	--	0.05	0.00
	400E	1.13	0.37	0.08	0.00
	1000E	--	--	0.09	0.00
	REFS	0.76	0.00	0.09	0.00
06 Jun 84	CNTR	--	--	--	--
	400E	1.00	0.09	--	--
	1000E	--	--	--	--
	REFS	0.91	0.00	--	--

* Each estimate was calculated through division of the concentration of PCB or Cu present in the field by the concentration of that material present in the BRH barrel material (6,910 ng/g and 2,900 µg/g for PCB and Cu, respectively). The high value was determined from the actual whole water concentration while the low estimate was calculated after the REFS values were subtracted from the other stations during that collection period.

based on PCB concentrations indicated the CNTR station was elevated compared with the REFS station. The same pattern was observed in both the Cu and PCB estimate for the 21 July 1983 sample. A decreasing concentration of BRH material was estimated moving away from the CNTR of the disposal mound.

114. On a temporal scale, the BRH concentrations (Cu data) decreased about half from June to July (high estimate). After this collection, however, the Cu-based BRH estimates fluctuated over time, with the December 1983 and June 1984 values being higher than the September 1983 concentrations. This pattern over time may be more reflective of CLIS than of actual BRH levels because these estimates (high value) were based on the absolute Cu levels at each location. Inspection of the low estimate indicated a more distinct pattern over the same time period. The BRH levels were highest immediately after the disposal operation June 1983 and generally decreased with increasing time. The low estimate provided here is more a measure of relative difference between the stations, after background LIS concentrations are subtracted (REFS). When trying to discern temporal trends, this estimate may be more appropriate.

115. The pattern of BRH exposure based on PCB water concentrations was very similar to that of Cu. The highest value was detected at the CNTR station in June 1983 and decreased both spatially and temporally with increasing time. In addition, the high estimates did not show the same variability over time that the Cu data did. This may indicate that PCB concentrations in LIS were more constant over time, and thus BRH estimates based on PCB concentrations were less influenced by background fluctuations.

116. Exposure to BRH exposure estimated from tissue residues. The first method used to estimate exposure conditions of *A. bairdii* to BRH material in CLIS involved the laboratory-generated relationships between PCB tissue residues and BRH exposures. Using this relationship and the PCB tissue residues in field-collected *A. bairdii*, estimates of field BRH exposure concentrations were calculated. There are three assumptions in this approach: (a) *A. bairdii* provide an integrated measure of exposure, (b) *A. bairdii* tissue residues were at equilibrium with BRH exposure concentrations at the time of sampling, and (c) PCBs are a good chemical marker for BRH sediments. Based on the results of the laboratory experiment, each of these assumptions seems reasonable.

117. The estimated exposures resulting from this approach are presented as milligrams per litre BRH for each station and collection date in Table 18. Sediment buried at CNTR were buried during disposal of the dredged material and

Table 18
Estimated Concentrations of BRH Sediment (mg/l) Suspended at
Sediment-Water Interface Based on PCB Concentrations
in Field-Collected *N. incisa*

Date	Station			
	CNTR	400E	1000E	REF
17 Apr 82	--	0	--	0
16 Nov 82	--	0	--	2
16 Feb 83	--	9	--	3
12 Apr 83	--	15	--	8
02 Jun 83	--	95	43	2
03 Jul 83	--	114	44	2
06 Sep 83	--	131	88	12
29 Nov 83	--	51	26	0
20 Mar 84	47	38	10	0
16 Oct 84	53	29	10	3
24 Jan 86	76	5	4	0

did not recolonize the dredged material mound until the spring of 1984. When the worms recolonized the mound, ERLN personnel began to sample them. The data in Table 18 display clear spatial and temporal trends. The highest estimates were in the immediate vicinity of the disposed BRH material (400E) during the summer of 1983. Exposure at 400E and 1000E decreased in 1984 and 1985.

118. *Nephtys incisa* exposure estimates from physical data. Benthic exposure at the FVP disposal site occurs through both the suspended and bedded sediments. This section describes the results of calculations of the maximum upper bound suspended sediment concentrations from 1 m above the bottom to the sediment-water interface. This calculation is based upon the assumption that the suspended solids at the sediment-water interface consist totally of BRH sediment and that the contaminant concentrations are similar to those found in the dredged material prior to disposal.

119. Total suspended solids concentrations were measured at the FVP site at 1 m above the sediment-water interface with an in situ monitoring platform (Bohlen and Winnick 1986). Although there is considerable variation in the

data through one tidal cycle, average background suspended solids were estimated to be 10 mg/l, while during typical storm conditions suspended solids concentrations averaged 30 mg/l for periods of 4 to 7 days (Munns et al. 1986).

120. Using an acoustic profilometer, the suspended sediment concentrations at 1 m above the bottom were found to increase exponentially to the sediment-water interface. The upper and lower limits for this increase are 10⁺ and 1⁻, respectively, depending on hydrographic conditions (Kohlen and Winnick 1986). These data, in conjunction with suspended sediment data for 1 m above the bottom, can be used to predict the suspended solids concentrations at the sediment-water interface.

121. For example, the suspended solids concentration under background conditions (10 mg/l) would increase to 100 mg/l for the 10⁺ enrichment at the sediment-water interface and decrease to 10 mg/l for the quiescent conditions. Likewise, under storm conditions (30 mg/l), sediment-water interface suspended solids concentrations would range from 300 to 30 mg/l for the 10⁺ and 1⁻ enrichments, respectively (Figure 26). These conditions represent the maximum upper bound exposures that would be expected to occur at the sediment-water interface and could be made using predisposal, site characterization data.

122. A more probable estimate is provided by using contaminant concentrations present in the dredged material after disposal. It is this material that will be resuspended and transported as suspended solids to populations outside the disposal site. Assuming that resuspended surficial sediments are the source of contaminants for the suspended sediments, the maximum upper bound estimates can be adjusted to reflect the spatial and temporal changes in contaminant concentration. These changes are represented as percentages of BRH sediment in the 0- to 2-cm surface layer at CNTR, 200E, 400E, and 1000E from immediately after disposal (June 1983) to October 1985 (Table 19). The combination of these percentages and the total suspended solids concentrations predicted for the sediment-water interface results in concentrations of BRH suspended sediments at the sediment-water interface for each station and sampling date (Table 20).

123. The sediment samples used for the percent calculations were not replicated; therefore, no variability estimates are available. However, certain trends in the data are evident (Table 19). The percentages of BRH sediment (as percent) at CNTR and 200E were low compared with the barre-

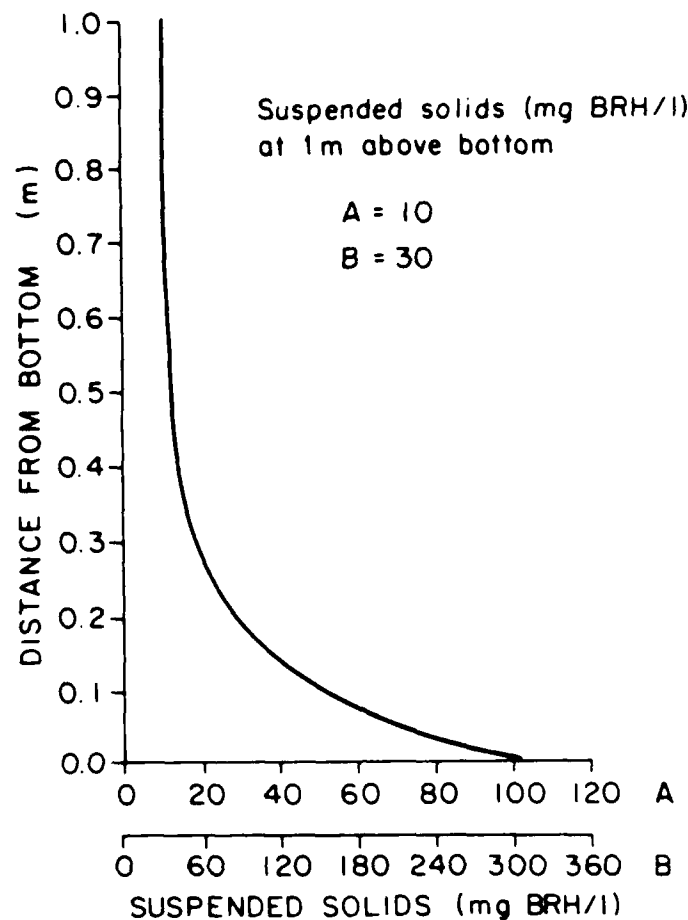


Figure 26. Suspended sediment concentrations from 1 m above the bottom to the sediment-water interface for storm and background conditions

sediments collected predisposal. There is a gradient of BRH material that is a function of both distance from the center of the mound and of time from disposal. BRH sediment concentrations were highest at CNTR and 200E immediately after disposal and decreased significantly through October 1984. Concentrations were elevated in December 1984 at CNTR and 200E and again in October 1985 at 200E. The BRH concentrations at 500E also decreased through time and, after March 1984, were only slightly higher than those at 1000E. These stations did not show the increased BRH concentration found at CNTR and 200E during the last two sampling dates. With the exception of the BRH concentration for December 1983, the concentrations at 2000E remained relatively similar throughout the study.

1.4. The 1- to 2-percent BRH sediment calculated for 1983 represents a

Table 19
Percent BRH Sediment in the Surficial Sediments
at the FVP Disposal Site

<u>Date</u>	<u>Station</u>			
	<u>CNTR</u>	<u>200E</u>	<u>400E</u>	<u>1000E</u>
Jun 83	44.5	41.1	12.5	1.8
Jul 83	15.0	37.4	3.3	1.6
Sep 83	32.0	36.7	4.9	2.0
Dec 83	32.8	36.1	9.5	4.4
Mar 84	4.4	2.2	1.9	1.8
Jun 84	9.5	15.6	0.5	0.7
Sep 84	10.0	0.8	3.5	0.5
Oct 84	2.6	--	0.2	1.6
Dec 84	35.1	11.3	0.0	1.0
Oct 85	0.2	21.0	0.0	0.0

Table 20
Concentration of BRH (mg/l) at the Sediment-Water Interface for
Total Suspended Sediment Concentrations of 10 and 30 mg/l
and an Enrichment of 10.*

<u>Date</u>	<u>Station</u>							
	<u>CNTR</u>		<u>200E</u>		<u>400E</u>		<u>1000E</u>	
	<u>300</u>	<u>100</u>	<u>300</u>	<u>100</u>	<u>300</u>	<u>100</u>	<u>300</u>	<u>100</u>
Jun 83	133.5	44.5	123.3	41.1	37.5	12.5	5.4	1.8
Jul 83	45.0	15.0	112.2	37.4	9.9	3.3	4.8	1.6
Sep 83	96.0	32.0	110.1	36.7	14.7	4.9	6.0	2.0
Dec 83	98.4	32.8	108.3	36.1	28.5	9.5	13.2	4.4
Mar 84	14.2	4.4	6.6	2.2	4.7	1.9	5.5	1.8
Jun 84	28.5	9.5	46.8	15.6	1.5	0.5	2.1	0.7
Sep 84	30.0	10.0	2.4	0.8	10.5	3.5	1.5	0.5
Oct 84	7.8	2.6	--	--	0.6	0.2	1.8	1.6
Dec 84	105.3	35.1	33.9	11.3	0	0	3.0	1.0
Oct 85	0.6	0.2	63.0	21.0	0	0	0	0

* BRH concentrations for the 1: enrichment can be obtained by dividing the tabular values by 10.

quantitatively measured elevation above background and is supported by tissue residue data for the infaunal polychaete *N. balthica*. Additional documentation of contamination comes from examination of the PAH centroid values, which indicate the presence of BKH sediment. This contamination could have resulted from the initial disposal operation, the errant disposal of BKH material in the vicinity of 1000F, or the continuous transport of contaminated material from the disposal site.

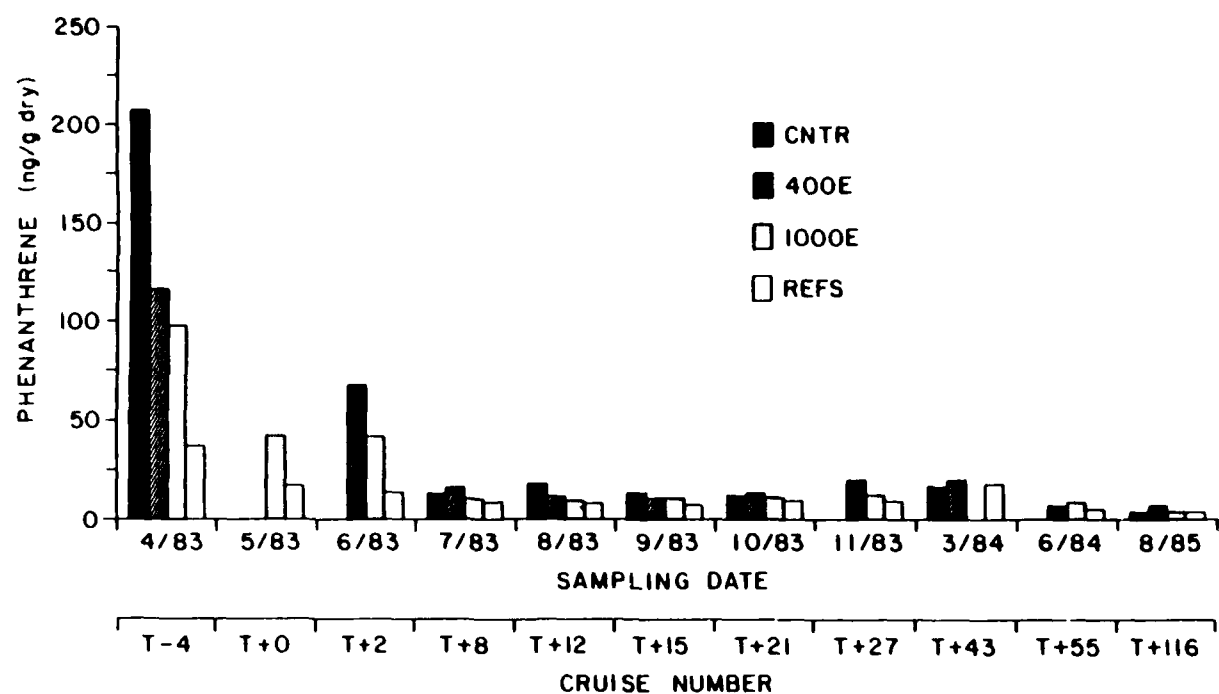
Tissue residues

125. Figure 3.12. The tissue residue levels for the mussels collected during the course of the FVP study are presented graphically in Figures 27-32 for each of the 12 selected organic, inorganic, and summary statistic chemical contaminants. The raw data shown on these figures are included in Appendix A.

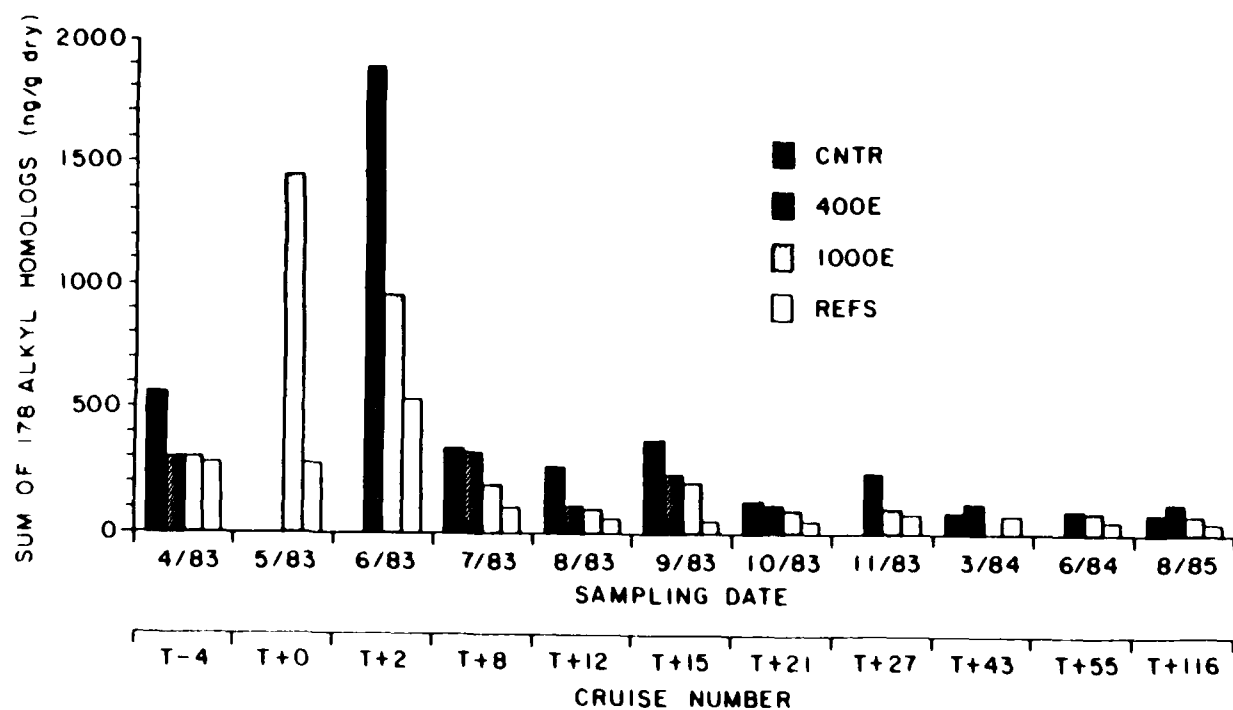
126. The PCB, ethylan, and PAH residues increased during the disposal operation. After completion of the disposal, tissue residues decreased to concentrations similar to those from predisposal deployments. The summary statistic SUM reflected the same pattern as most of the PAH compounds.

127. A consistent pattern emerged when the spatial component of the organic residue data was considered within a sampling date. Figure 3.13 were deployed during the actual disposal operation and were collected at T + 0 and T + 2. For the T + 0 collection, only the 1000F and REFS stations were recovered. The tissue residue concentration for each organic compound was uniformly higher at the 1000F station than at REFS. The T + 2 collection included data from three stations, 400E, 1000F, and REFS. Once again, a consistent pattern was seen in the residue data, with mussels at 400E exhibiting the highest concentrations for each compound, followed by the 1000F and REFS stations. After the completion of disposal, the differences in tissue residue concentrations between stations decreased dramatically.

128. The tissue residue data for metals did not provide as clear a picture of the disposal operation as the organic residues did. In general, metal residue concentrations increased slightly during the disposal operation, after which they decreased to levels well below those present during the predisposal collection (T = 0). Metal concentrations were elevated in the samples collected in October and November 1984, but not in the T + 2 samples, which were collected even during the disposal operation (T + 0 and T + 2). The October and November samples consisted of organisms that had been taken from the site

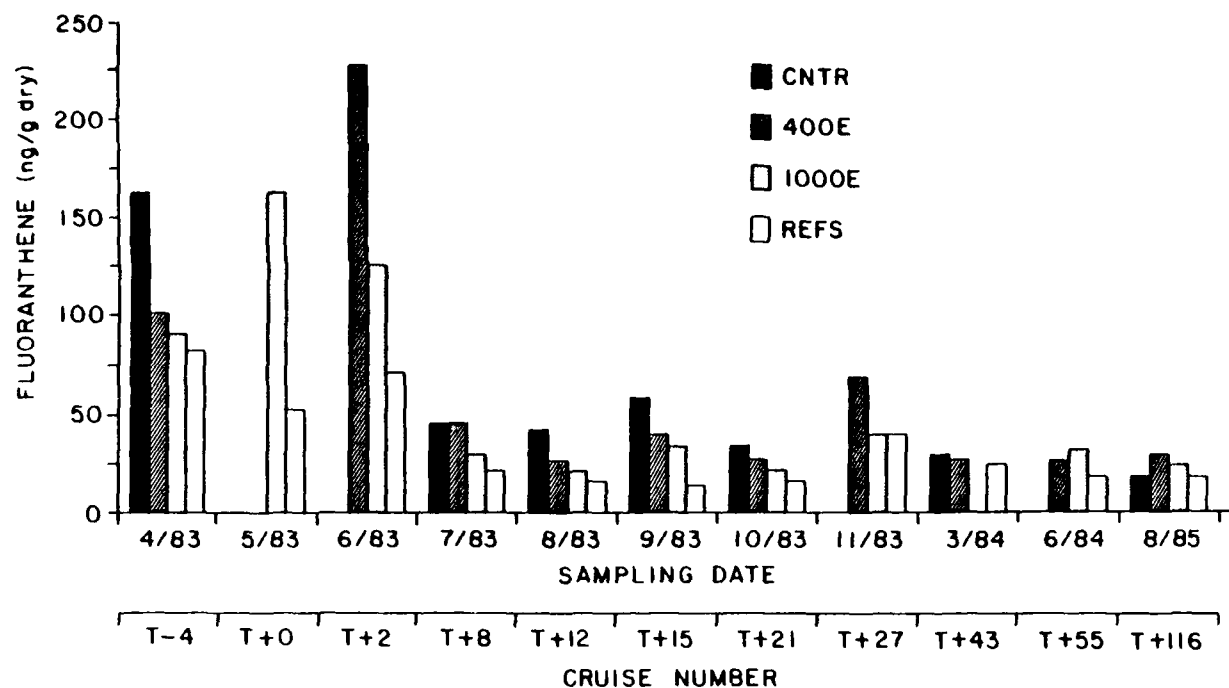


a. Phenanthrene

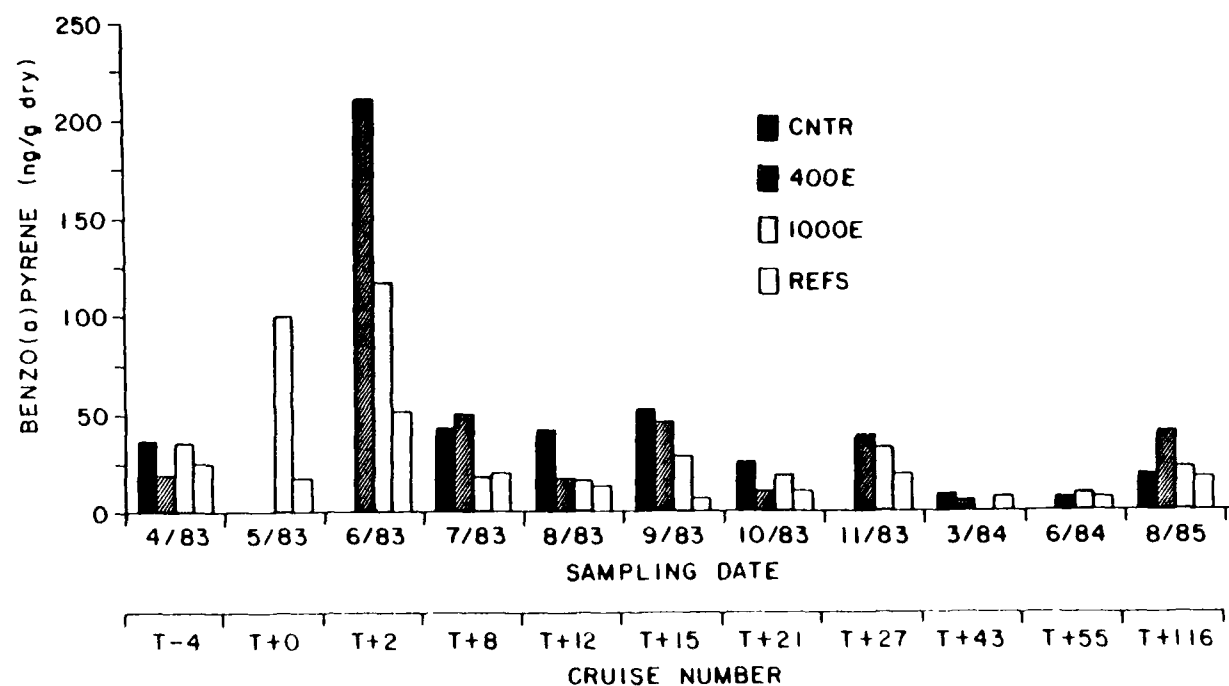


b. 178 alkyl homologs

Figure 27. Concentrations of phenanthrene and the 178 alkyl homologs in the tissues of 178 alkyl homologs exposed at the specified IYP stations and sampling dates.

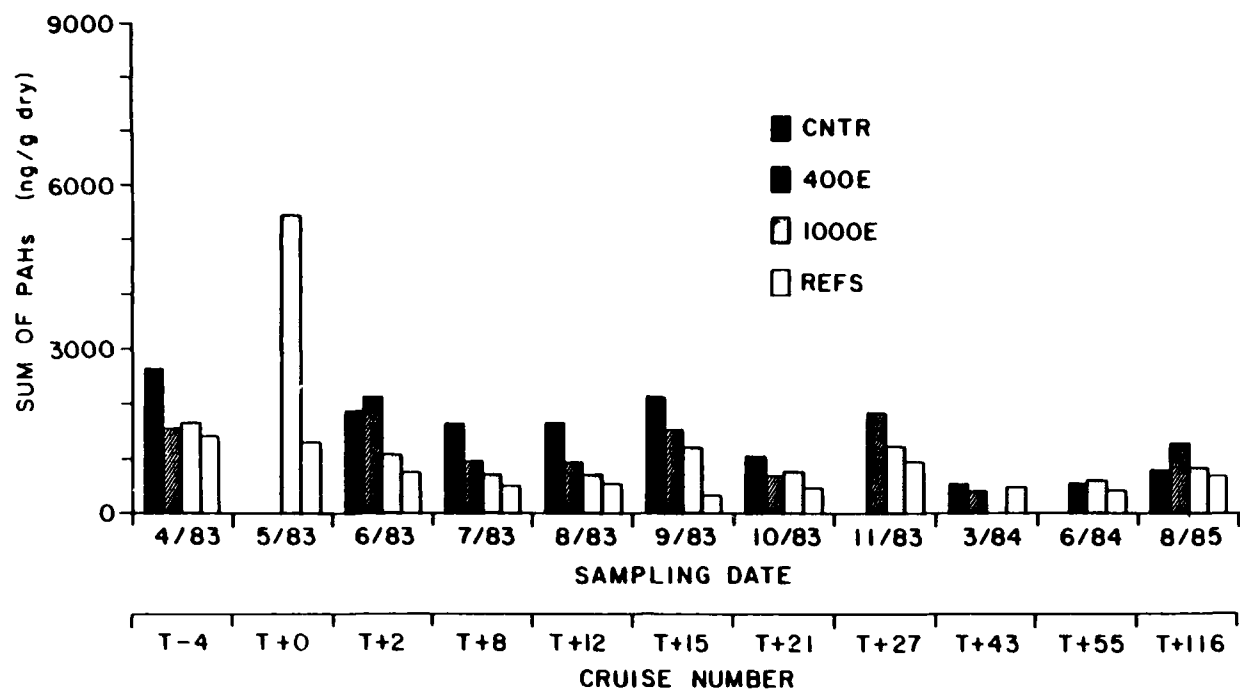


a. Fluoranthene

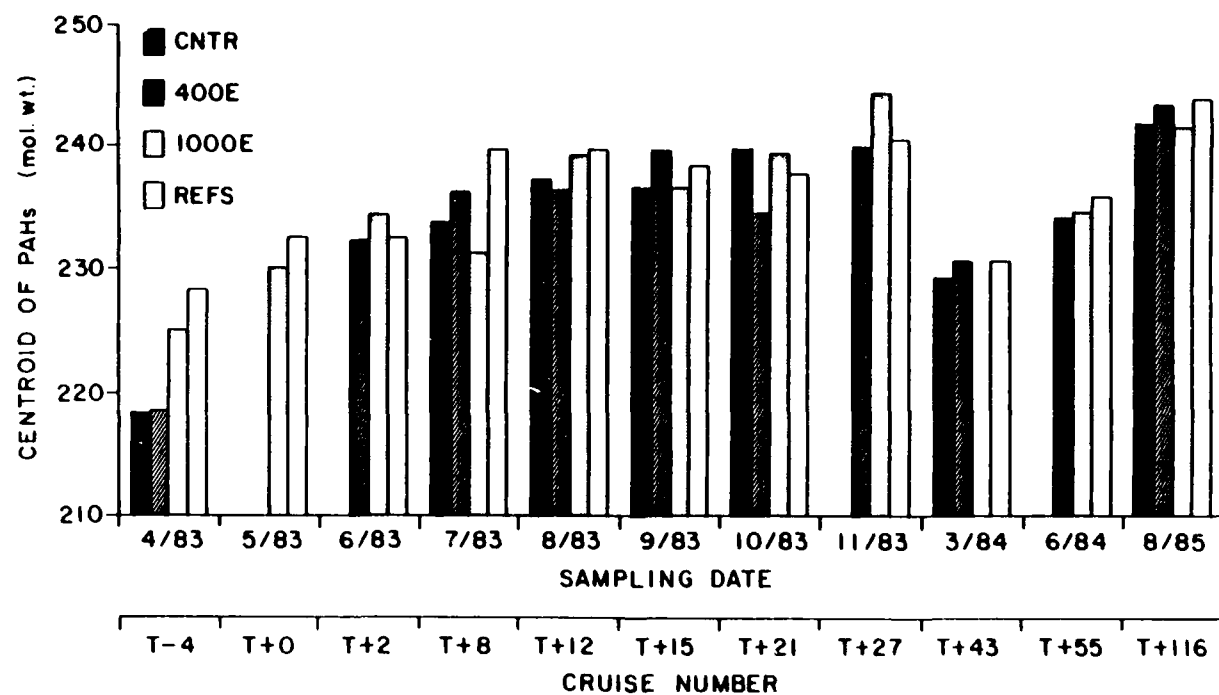


b. Benzo(a)pyrene

Figure 28. Concentrations of fluoranthene and benzo(a)pyrene in the tissues of *M. edulis* exposed at the specified RVP stations and sampling dates

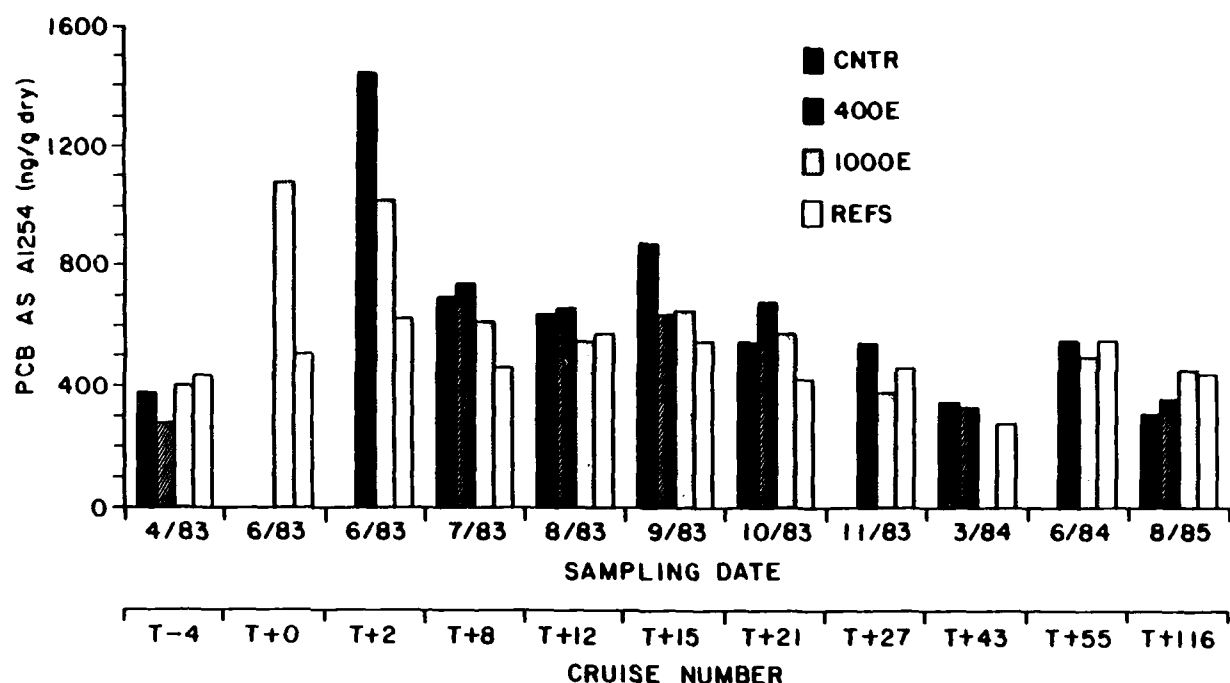


a. SUM

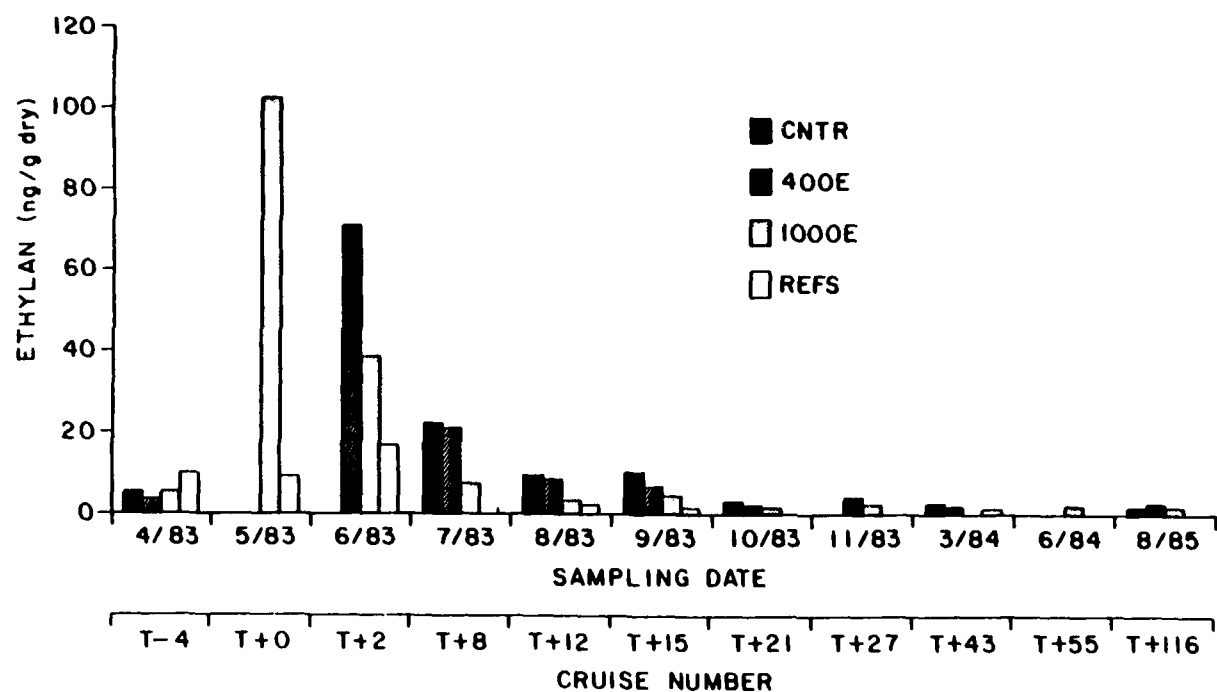


b. CENT

Figure 29. Concentrations of the SUM of the PAHs and CENT in the tissues of *M. edulis* exposed at the specified FVP stations and sampling dates

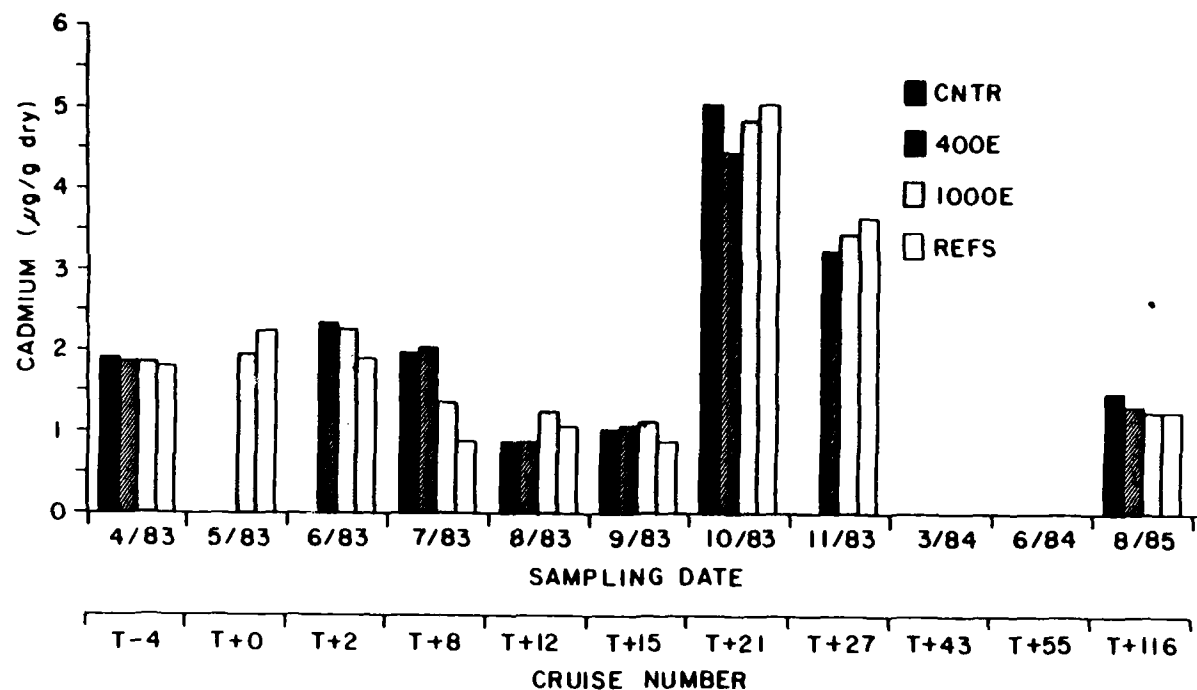


a. PCBs as A1254

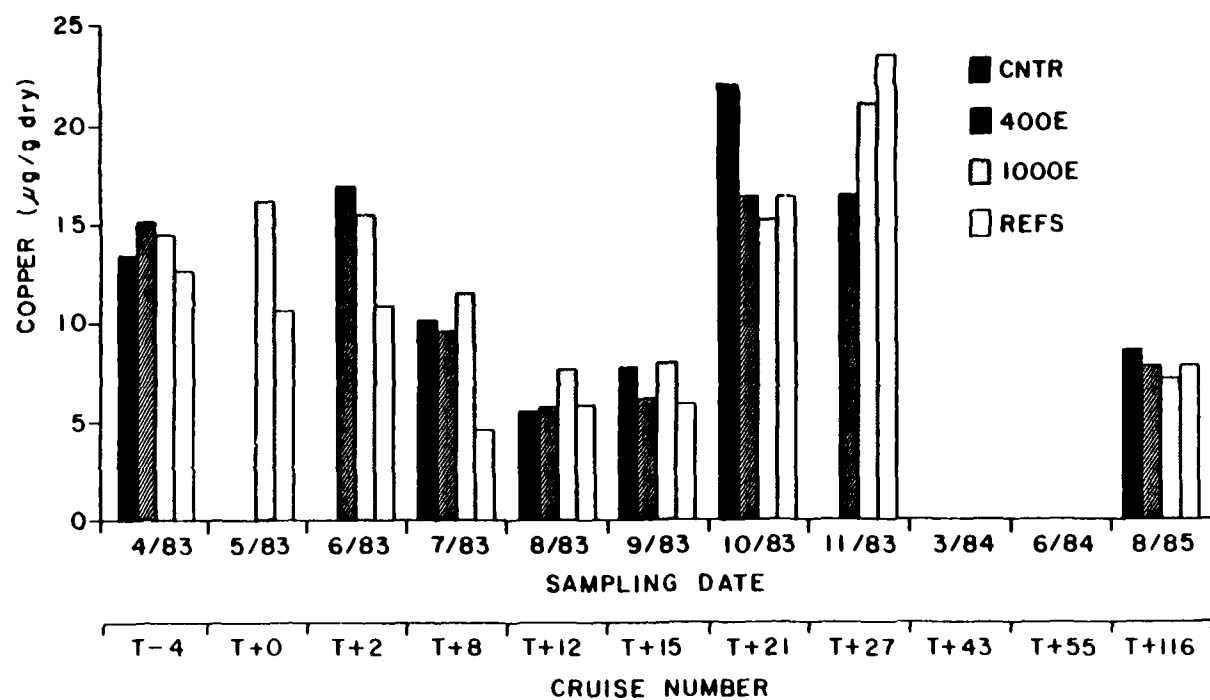


b. Ethylan

Figure 30. Concentrations of PCBs as A1254 and ethylan in the tissues of *M. edulis* exposed at the specified FVP stations and sampling dates

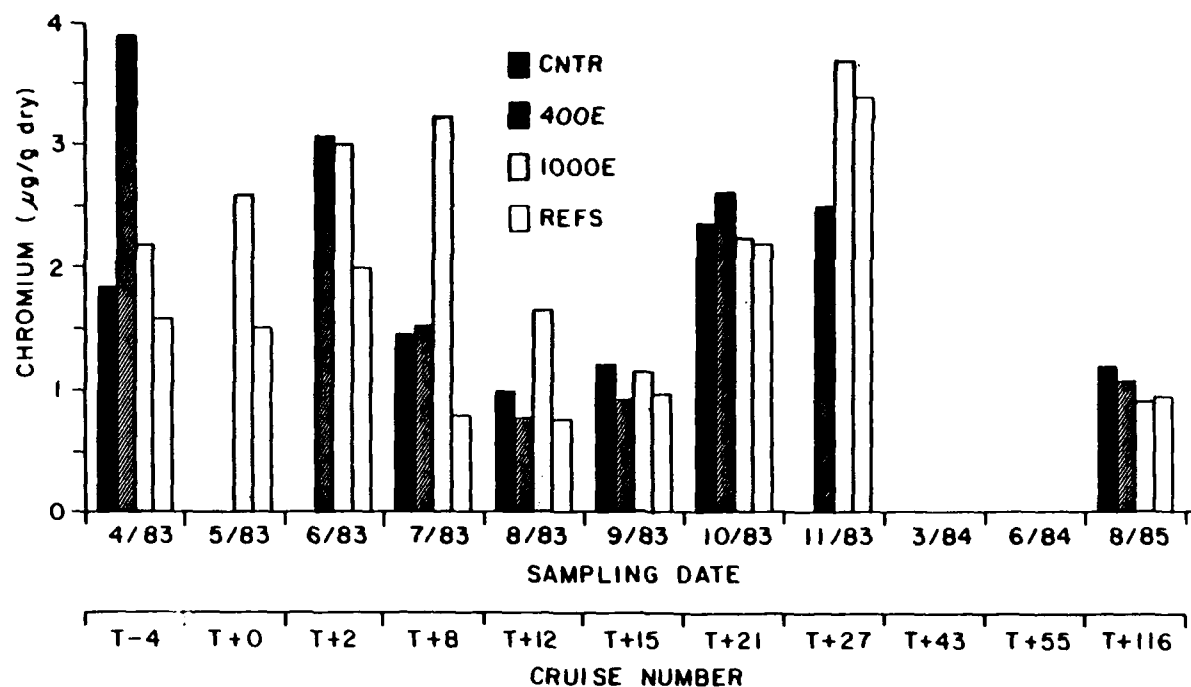


a. Cadmium

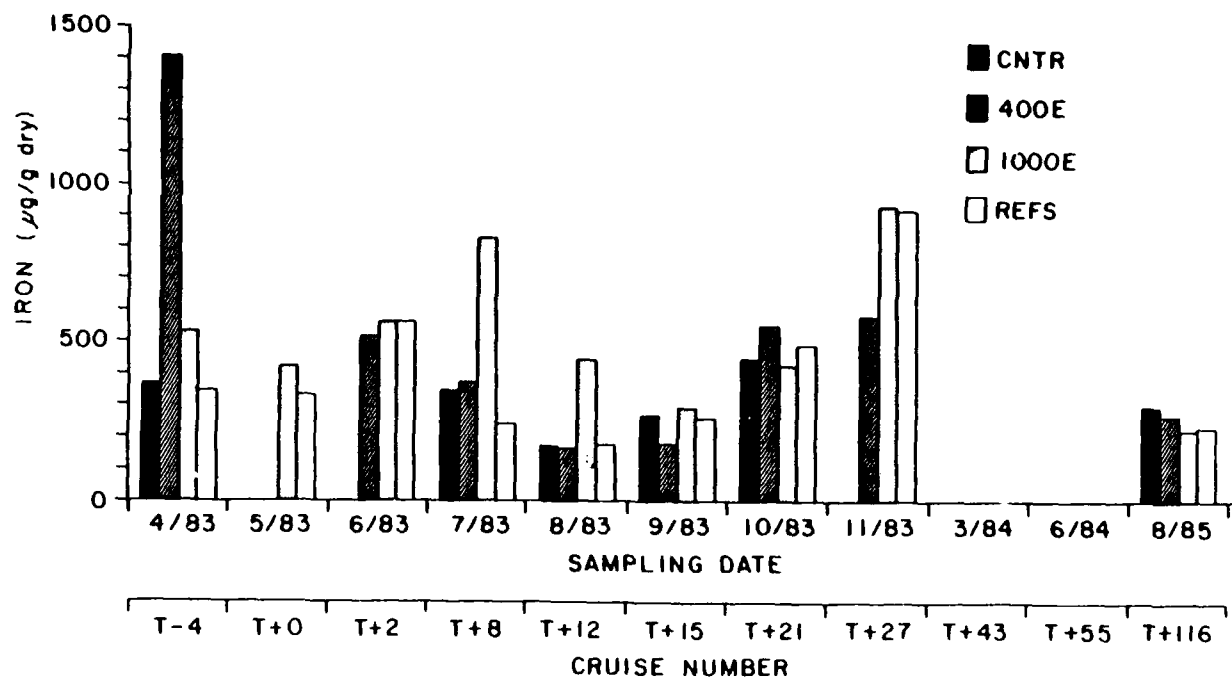


b. Copper

Figure 31. Concentrations of cadmium and copper in the tissues of *M. edulis* exposed at the specified FVP stations and sampling dates



a. Chromium



b. Iron

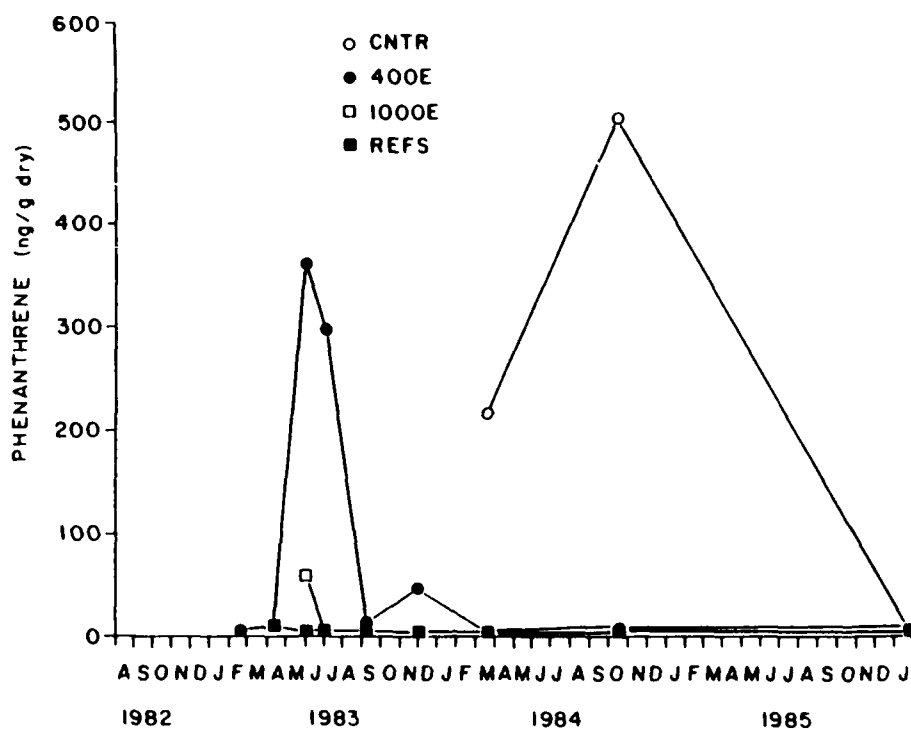
Figure 32. Concentrations of chromium and iron in the tissues of *K. edulis* exposed at the specified FVP stations and sampling dates

for 7 months and 3 months, respectively. One possible explanation for the difference between elevated metal and organic tissue residue patterns may be that mussels require a longer period of time to reach steady-state with respect to metal concentrations. Comparing the organic and metal residue data from the field suggests that organic tissue residues present a better picture of the disposal operation at the FVP disposal site.

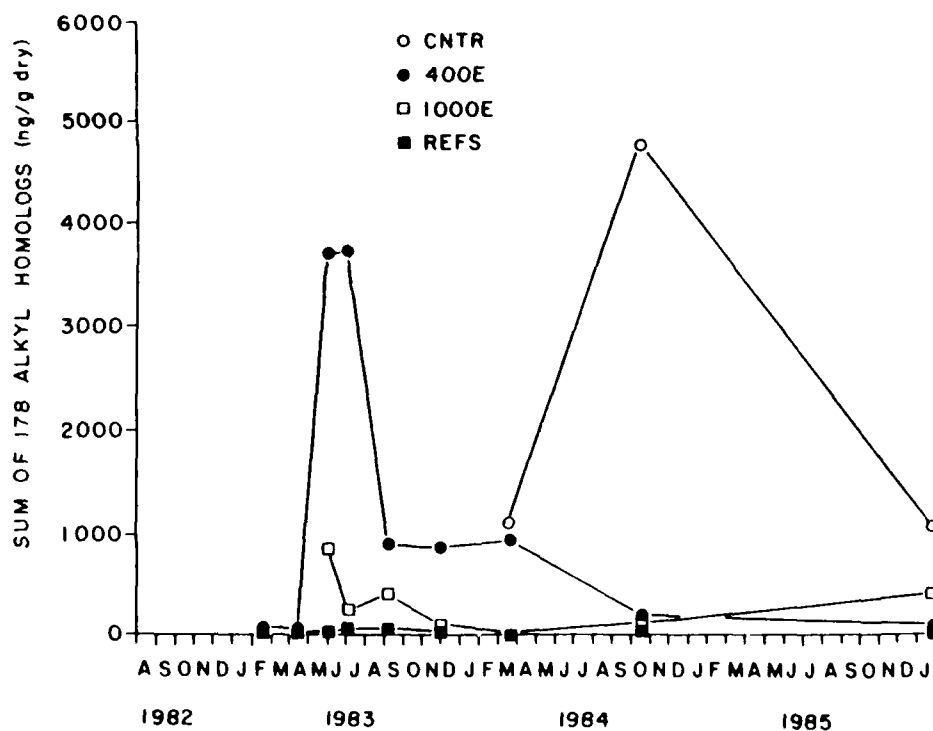
129. *Nephtys incisa*. The tissue concentrations for the *N. incisa* collected at the CLIS site during the FVP study are presented graphically for each of the 12 selected chemical variables in Figures 33-38. The raw data shown on these figures are included in Appendix A, Tables A14-28.

130. Clear spatial and temporal patterns of tissue concentrations of PCBs and PAHs were found. Highest tissue concentrations were determined at station 400E with lowest concentrations at station REFS. When *N. incisa* recolonized the dredged material site at station CNTR in the spring of 1984, the tissue concentrations of PCBs in these worms were comparable with those found at 400E immediately postdisposal.

131. There was a pattern of increased tissue concentrations of PCBs and PAHs during the summer of 1983. The PCB concentration peaked in September, 4 months postdisposal, and then declined towards background concentration over a 2-year period (Figure 36). The steady increase of PCB tissue concentrations indicated continuous exposure to contaminated sediments during this 4-month period even at station 1000E. No significant storms occurred during the summer of 1983. Therefore, the contaminant exposures at station 1000E were probably due to initial dispersion of contaminated BRH sediments during disposal or to tidally driven resuspension and movement of BRH sediments from the dredged material mound. In contrast to the 4-month period of PCB increase, the highest PAH tissue concentrations occurred in July, only 2 months postdisposal. The laboratory data clearly suggest that *N. incisa* have the ability to metabolize PAHs and that this metabolic capability was induced during the 42-day experimental period. The tissue residue data for PCBs in field worms indicate high levels of exposure to BRH contaminants at stations 400E and 1000E for 4 months postdisposal. Yet, the tissue residue data for PAHs in these same samples peaked in 2 months and declined sharply by September 1983. These data clearly suggest that the metabolism of PAHs was induced and was causing a sharp decline in tissue residue PAH concentrations despite continuous exposure to these compounds.

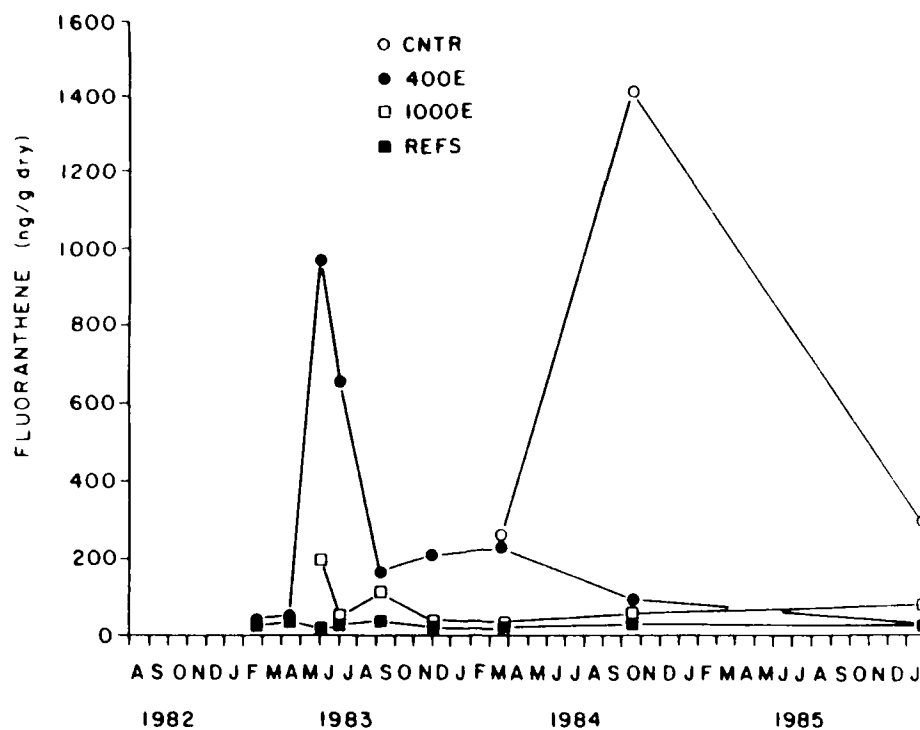


a. Phenanthrene

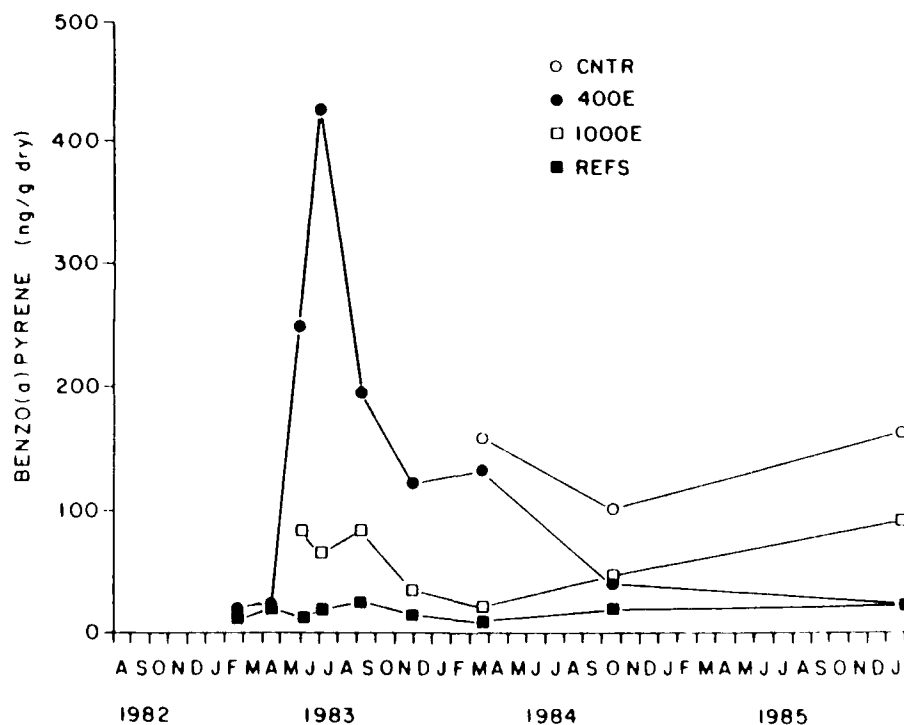


b. 178 alkyl homologs

Figure 33. Concentrations of phenanthrene and the 178 alkyl homologs in the tissues of *E. inesa* collected at the specified FVP stations and sampling dates

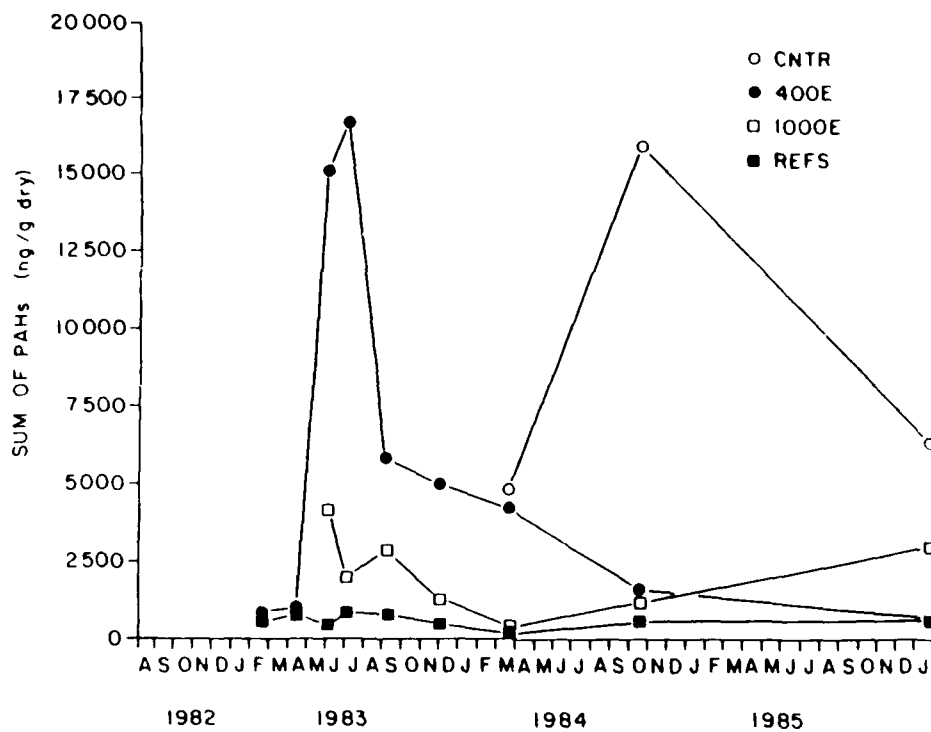


a. Fluoranthene

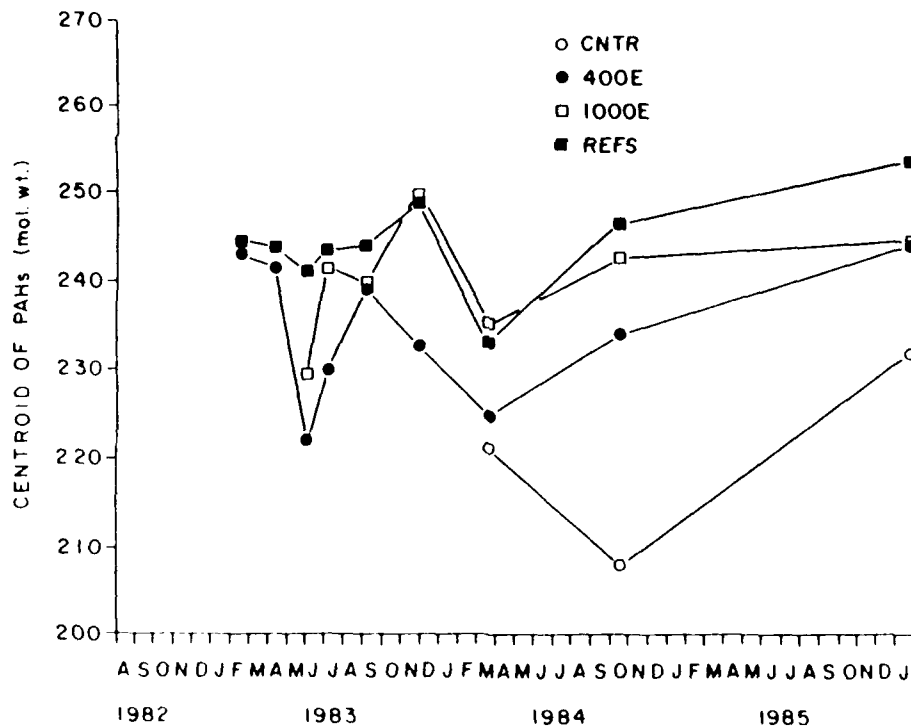


b. Benzo(a)pyrene

Figure 34. Concentrations of fluoranthene and benzo(a)pyrene in the tissues of *M. balthica* collected at the specified EYP stations and sampling dates

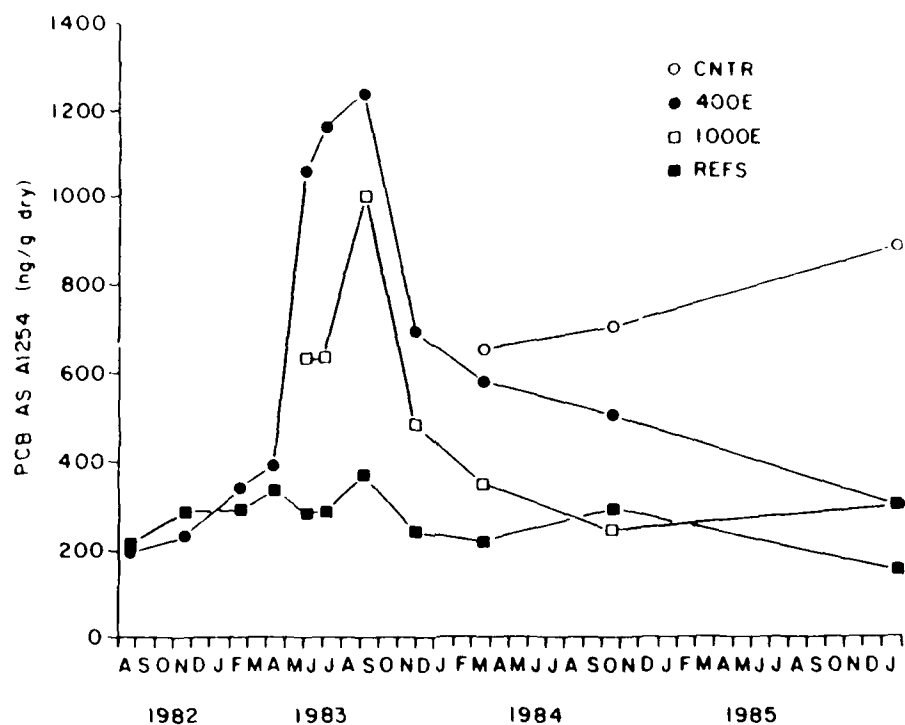


a. SUM of PAHs

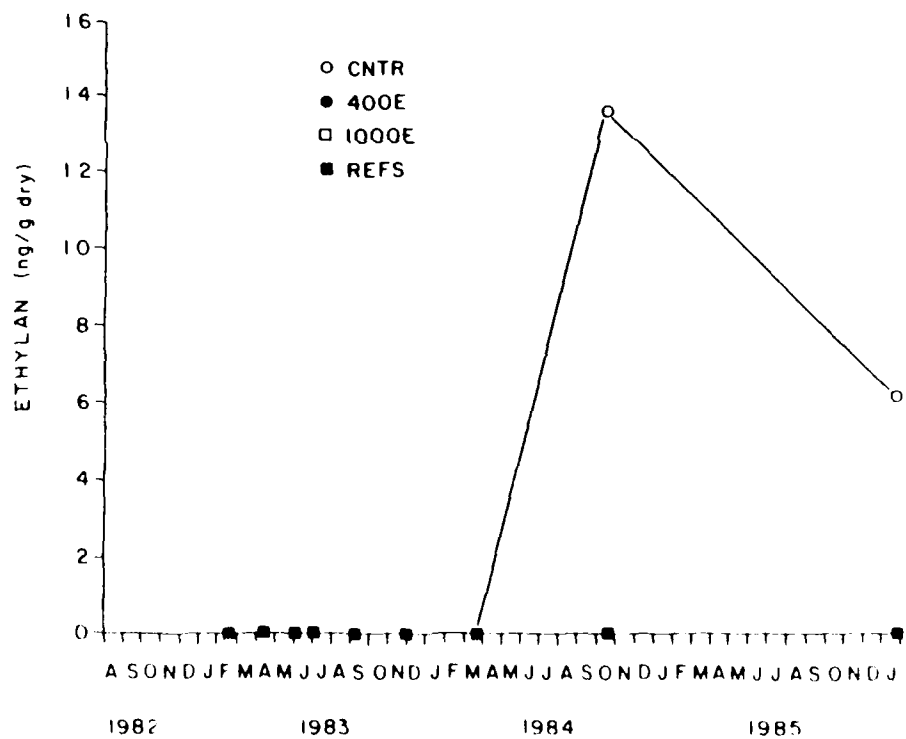


b. CENT of PAHs

Figure 35. Concentrations of the SUM of the PAHs and CENT in the tissues of *M. balthica* collected at the specified FVP stations and sampling dates



a. PCBs as A1254



b. Ethylan

Figure 36. Concentrations of PCBs as A1254 and ethylan in the tissues of *L. borealis* collected at the specified FVP stations and sampling dates.

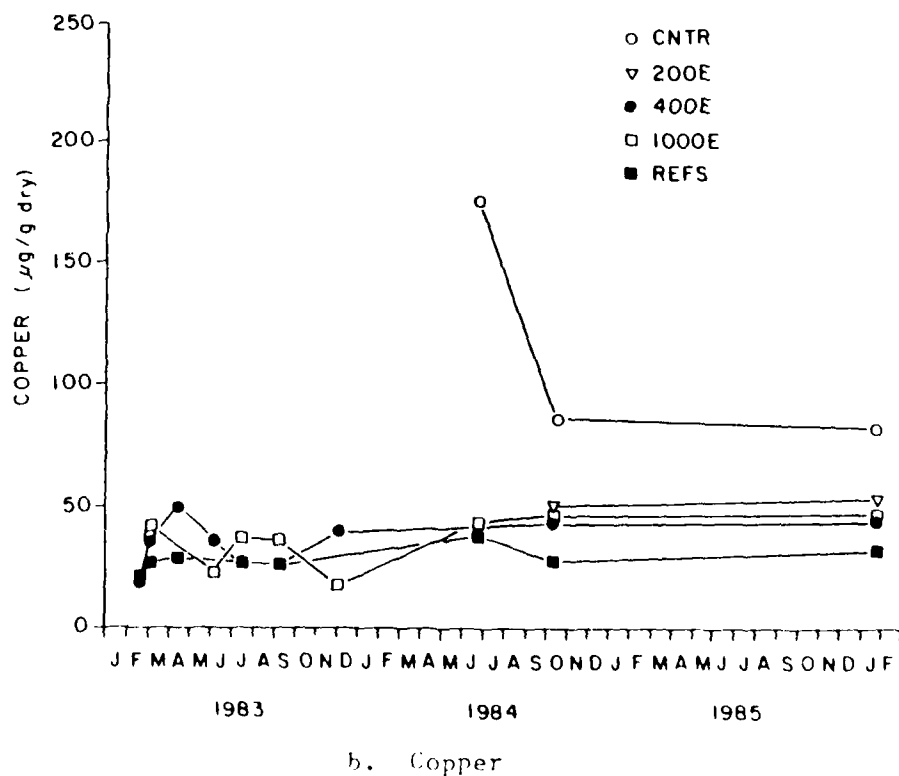
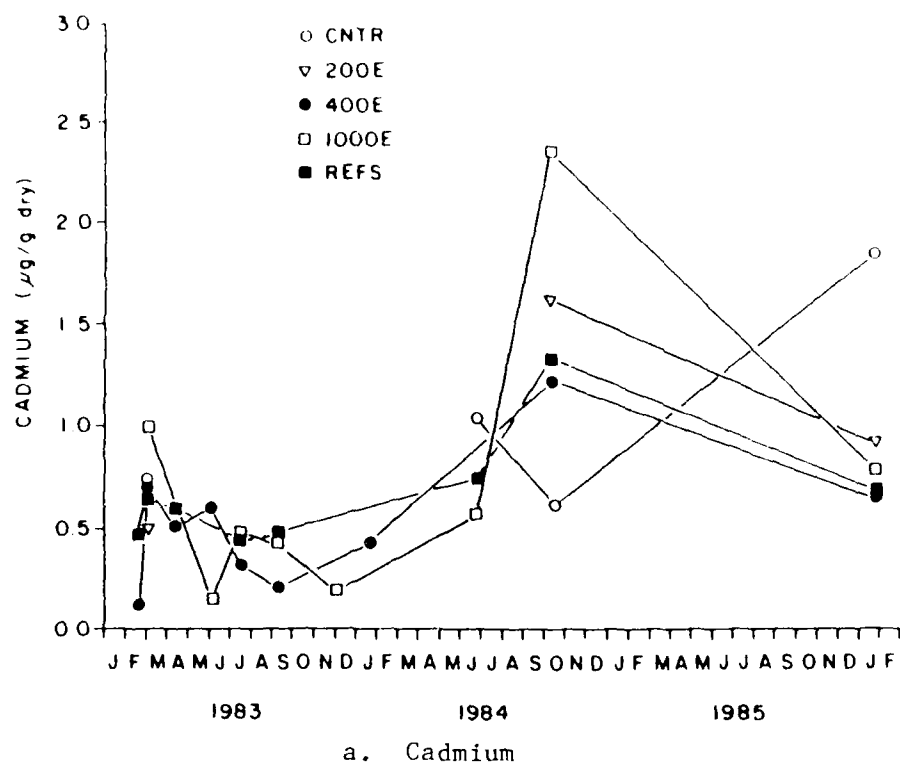
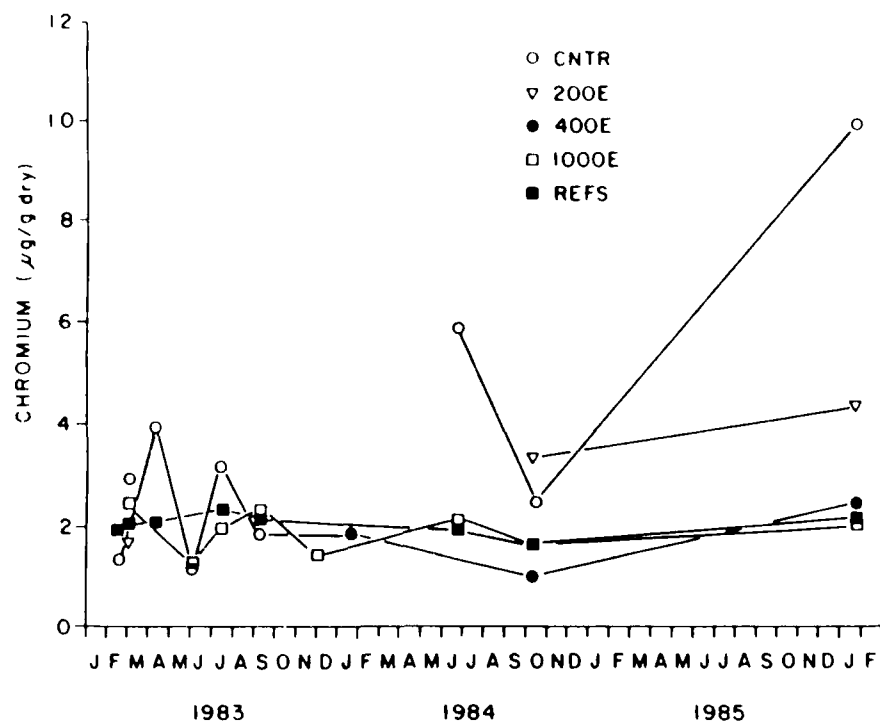
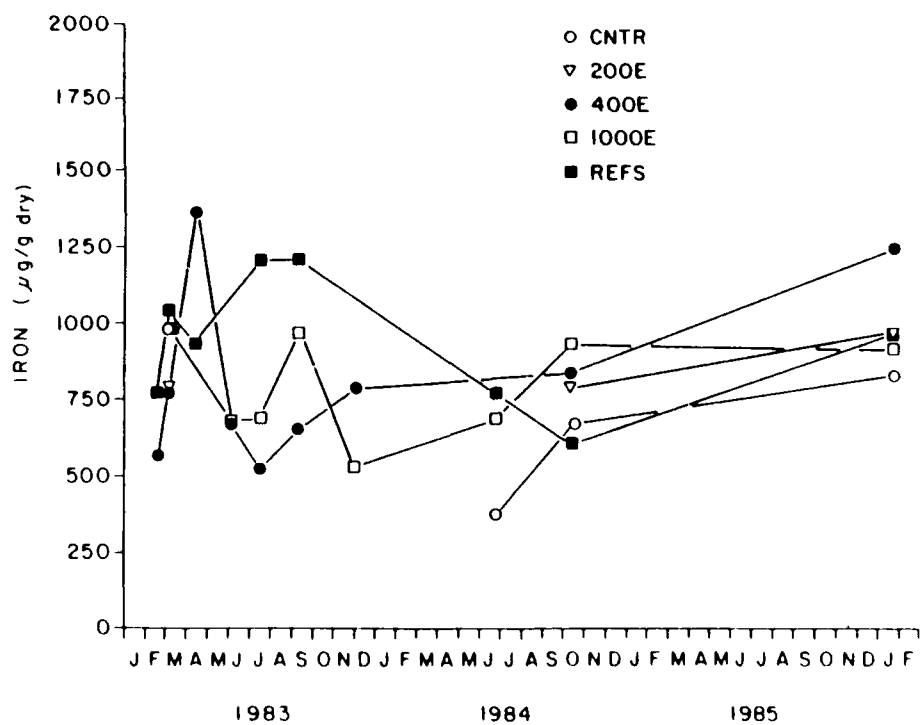


Figure 37. Concentrations of cadmium and copper in the tissues of *L. forbesi* collected at the specified FVP stations and sampling dates



a. Chromium



b. Iron

Figure 38. Concentrations of chromium and iron in the tissues of *L. inermis* collected at the specified FVP stations and sampling dates.

132. The temporal patterns of the field tissue residues showed a rapid increase in organic residue values during and immediately postdisposal at 400E and 1000E. The PAH residues for *N. incisa* showed an increase immediately postdisposal. This was followed by a rapid decline during July and August. The phenanthrene residue value returned to background levels by September, but the higher molecular weight PAH tissue residues tended to remain at approximately 24 percent of their maximum values for an additional year. The PCB residues at 400E increased rapidly immediately after disposal and, unlike the PAHs, remained elevated through September and declined only 50 percent by December 1983. Unlike the PAHs, PCB residues at 1000E postdisposal increased 2.5 times that at REFS and remained elevated above REFS until October 1984. There were no clear temporal or spatial patterns for inorganic tissue residues for *N. incisa* from the field.

133. *Mytilus edulis*. No histopathological changes were noted in the mussels collected from the sampling stations at the BRH disposal site (Table 21). In all cases, the appearance of the cells and tissues examined was within the range of expected histology for normal *Mytilus edulis* collected in New England waters. To illustrate the absence of histological effects, the reproductive tract and gills from *M. edulis* exposed at 400E immediately after disposal (T + 2 weeks) are presented in Figures 39 and 40. During this period, effects on scope for growth were clearly evident (Nelson et al. 1987), and tissue residues for the major contaminants were the highest reported for this species at any time during the study. Therefore, even during the period of apparent maximum environmental exposure, no histological effects were detected.

134. *Nephtys incisa*. No substantive histopathological changes were noted in *Nephtys incisa* collected from the various stations at the BRH disposal site (Table 22). The epidermal thickening and darkening observed in the laboratory studies were not detected in any of the field samples (Figure 41). Periods of maximum exposure of *N. incisa* to BRH sediments were determined from tissue residues to occur at T + 8 to T + 16 at 400E. No histopathological effects were detected for any of the organ systems examined in *N. incisa* during this period (Figure 42).

Table 1
Histopathological Findings for *T. rubra* Deployed at
the BKN Disposal Site

Deployment Period	Station	N*	Organs Examined, Percent Showing Change						
			Repro Fract**	Heart	Gills	Kidney	Tract†	Muscle	Gyssus Organ
T - 4	CNTR	25	0	0	0	0	0	0	0
	400E	25	0	0	0	0	0	0	0
	1000E	25	0	0	0	0	0	0	0
	REFS	25	0	0	0	0	0	0	0
T + 2	CNTR	--							
	400E	25	0	0	0	0	0	0	0
	1000E	25	0	0	0	0	0	0	0
	REFS	25	0	0	0	0	0	0	0
T + 8	CNTR	25	0	0	0	0	0	0	0
	400E	25	0	0	0	0	0	0	0
	1000E	25	0	0	0	0	0	0	0
	REFS	25	0	0	0	0	0	0	0
T + 12	CNTR	26	0	0	0	0	0	0	0
	400E	25	0	0	0	0	0	0	0
	1000E	25	0	0	0	0	0	0	0
	REFS	25	0	0	0	0	0	0	0
T + 16	CNTR	25	0	0	0	0	0	0	0
	400E	25	0	0	0	0	0	0	0
	1000E	25	0	0	0	0	0	0	0
	REFS	25	0	0	0	0	0	0	0
T + 22	CNTR	25	0	0	0	0	0		
	400E	25	0	0	0	0	0		
	1000E	25	0	0	0	0	0		
	REFS	25	0	0	0	0	0		
T + 23	CNTR	--							
	400E	25	0	0	0				
	1000E	25	0	0					
	REFS	25	0						

AD-A100 152

FIELD VERIFICATION PROGRAM (AQUATIC DISPOSAL) EFFECTS
OF BLACK ROCK HARBO. (U) ARMY ENGINEER WATERWAYS
EXPERIMENT STATION VICKSBURG MS ENVIR..

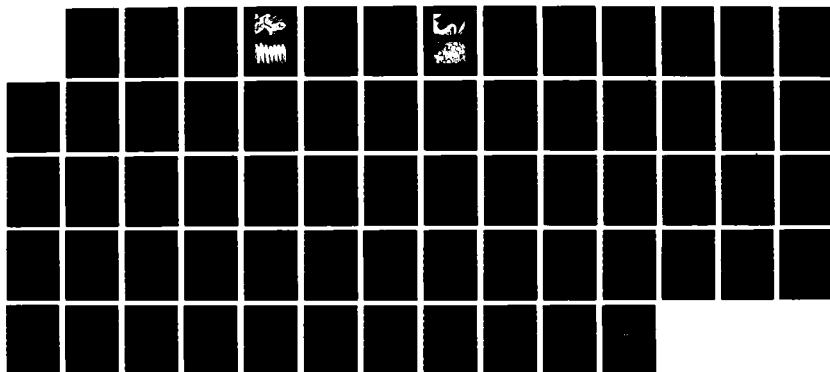
2/2

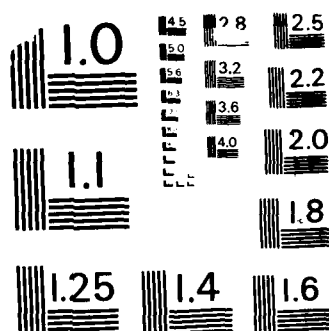
UNCLASSIFIED

P P YEVICH ET AL. SEP 87 NES/TR/D-87-8

F/G 8/1

NL





MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

Table 21
Histopathological Findings for *M. edulis* Deployed at
the BRH Disposal Site

Deployment Period	Station	N*	Organs Examined, Percent Showing Change						Byssus Organ
			Repro Tract**	Heart	Gills	Kidney	GI Tract†	Muscle	
T - 4	CNTR	25	0	0	0	0	0	0	0
	400E	25	0	0	0	0	0	0	0
	1000E	25	0	0	0	0	0	0	0
	REFS	25	0	0	0	0	0	0	0
T + 2	CNTR	--							
	400E	25	0	0	0	0	0	0	0
	1000E	25	0	0	0	0	0	0	0
	REFS	25	0	0	0	0	0	0	0
T + 8	CNTR	25	0	0	0	0	0	0	0
	400E	25	0	0	0	0	0	0	0
	1000E	25	0	0	0	0	0	0	0
	REFS	25	0	0	0	0	0	0	0
T + 12	CNTR	26	0	0	0	0	0	0	0
	400E	25	0	0	0	0	0	0	0
	1000E	25	0	0	0	0	0	0	0
	REFS	25	0	0	0	0	0	0	0
T + 16	CNTR	25	0	0	0	0	0	0	0
	400E	25	0	0	0	0	0	0	0
	1000E	25	0	0	0	0	0	0	0
	REFS	25	0	0	0	0	0	0	0
T + 22	CNTR	25	0	0	0	0	0	0	0
	400E	25	0	0	0	0	0	0	0
	1000E	25	0	0	0	0	0	0	0
	REFS	25	0	0	0	0	0	0	0
T + 23	CNTR	--							
	400E	25	0	0	0	0	0	0	0
	1000E	25	0	0	0	0	0	0	0
	REFS	25	0	0	0	0	0	0	0

(Continued)

- * N = Number of animals examined.
 ** Repro Tract = Reproductive tract.
 † GI Tract = Gastrointestinal tract.

Table 21 (Concluded)

Deployment Period	Station	N*	Organs Examined, Percent Showing Change						
			Repro Tract**	Heart	Gills	Kidney	GI Tract†	Muscle	Byssus Organ
T + 40	CNTR	29	0	0	0	0	0	0	0
	400E	25	0	0	0	0	0	0	0
	1000E	--							
	REFS	30	0	0	0	0	0	0	0
T + 55	CNTR	--							
	400E	22	0	0	0	0	0	0	0
	1000E	29	0	0	0	0	0	0	0
	REFS	16	0	0	0	0	0	0	0
T + 74	CNTR	--							
	400E	24	0	0	0	0	0	0	0
	1000E	25	0	0	0	0	0	0	0
	REFS	25	0	0	0	0	0	0	0



Figure 39. *Mytilus edulis*, portion of reproductive tract from animal collected at 400E on T + 2. Photomicrograph shows normal ova, cytoplasm, and vitelline membrane



Figure 40. *Mytilus edulis*, gills from animal collected at 400E at T + 2. Photomicrograph shows normal gill structure for *M. edulis*

Table 22
Histopathological Findings for *N. incisa* Collected
at the BRH Disposal Site

Collection Period	Station	N*	Organs Examined, Percent Showing Change				
			Epidermis	Muscle	Repro Tract**	System	GI Tract†
T - 13	400E	57	0	0	0	0	0
	1000E	42	0	0	0	0	0
	REFS	44	0	0	0	0	0
T - 9	400E	34	0	0	0	0	0
	1000E	38	0	0	0	0	0
	REFS	38	0	0	0	0	0
T - 5	400E	44	0	0	0	0	0
	1000E	51	0	0	0	0	0
	REFS	75	0	0	0	0	0
T - 1	REFS	37	0	0	0	0	0
T + 2	200E	29	0	0	0	0	0
	400E	43	0	0	0	0	0
	1000E	32	0	0	0	0	0
	REFS	41	0	0	0	0	0
T + 8	200E	34	0	0	0	0	0
	400E	24	0	0	0	0	0
	1000E	41	0	0	0	0	0
	REFS	30	0	0	0	0	0
T + 12	200E	20					
	400E	25	0	0	0	0	0
	1000E	23	0	0	0	0	0
	REFS	35	0	0	0	0	0
T + 16	200E	25	0	0	0	0	0
	400E	25	0	0	0	0	0
	1000E	25	0	0	0	0	0
	REFS	26	0	0	0	0	0
T + 28	400E	38	0	0	0	0	0
	1000E	38	0	0	0	0	0
	REFS	34	0	0	0	0	0

(Continued)

- * N = Number of animals examined.
 ** Repro Tract = Reproductive tract.
 † GI Tract = Gastrointestinal tract.

Table 22 (Concluded)

Collection Period	Station	N*	Organs Examined, Percent Showing Change				
			Epidermis	Muscle	Repro Tract**	System	GI Tract†
T + 40	200E	5	0	0	0	0	0
	400E	43	0	0	0	0	0
	1000E	58					
	REFS	35	0	0	0	0	0
T + 55	200E	21					
	400E	53	0	0	0	0	0
	1000E	46	0	0	0	0	0
	REFS	40	0	0	0	0	0
T + 74	200E	12					
	400E	53	0	0	0	0	0
	1000E	50	0	0	0	0	0
	REFS	49	0	0	0	0	0
T + 117	200E	30	0	0	0	0	0
	400E	25	0	0	0	0	0
	1000E	22	0	0	0	0	0
	REFS	27	0	0	0	0	0



Figure 41. *Nephtys incisa*, epidermis from animals collected at 400E at T + 16. Arrow points to epithelium that is a single cell thick and composed of simple squamous to cuboidal cells

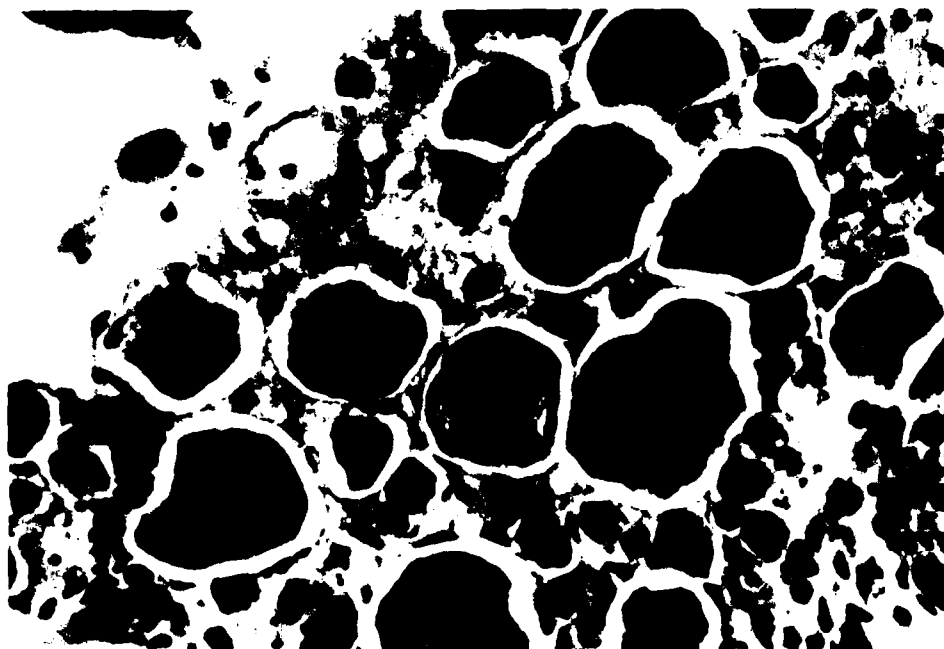


Figure 42. *Nephtys incisa*, developing ova from animal collected at 400E on T + 16. Arrow points to nucleus of oocyte

PART IV: DISCUSSION

Laboratory Studies

Mytilus edulis

135. *Mytilus edulis* exposed continuously to suspended BRH sediments exhibited histopathological changes in the reproductive tract, gills, kidney, and gastrointestinal tract. Minor changes were observed in the byssus organ. The incidence of histopathological change noted within a given organ was related to the concentration of BRH sediment that ranged from 1 to 10 mg/l for 14- to 28-day exposures. The gills were the most severely affected, with pathology incidences of 80 to 100 percent at exposure concentrations of 1 to 3 mg/l of BRH sediment. The gastrointestinal tract showed pathology incidences of 7, 50, and 65 percent at exposures of 3, 5, and 10 mg/l of BRH sediment. Reproductive effects were also related to exposure, with incidences of 20 and 50 percent at 3- and 10-mg/l BRH sediment, whereas the incidence of kidney lesions ranged from 7 to 25 percent at exposures of 3 and 10 mg/l of BRH sediment, respectively. In previous studies with *M. edulis* employing somewhat different BRH sediment exposures, histopathological effects were reported for the female reproductive tract and the heart (Yevich et al. 1986).

Nephtys incisa

136. *Nephtys incisa* exposed to suspended BRH sediment in bedded reference sediment exhibited only one histological change, which involved the thickening and darkening of the parapodial epidermis. This same response was also reported in previous studies on BRH sediment (Yevich et al. 1986). This response appears to result from contact with BRH sediment. It does not appear to be a pathological condition and has not been treated as such in this report.

Field Studies

Mytilus edulis

137. No effects were observed in any of the seven organ systems examined from *M. edulis* deployed at FVP disposal site stations. The explanation for this can be found when field exposure concentrations of BRH sediment are compared with laboratory exposure concentrations. Field exposures were

quantified through the use of physical models and from tissue residue data. Both of these methods of analysis indicate that, with the exception of during and within 1 month after disposal, the exposure of *M. edulis* to BRH sediment at the FVP stations was similar to REFS site and predisposal conditions. This is supported by tissue residue data (Figures 27-32), chemical data (Table 17), and the results of cluster analysis of the tissue residue data.

Nephtys incisa

138. No histopathological changes were noted in *N. incisa* collected at the FVP site sampling stations during this program. As has been seen from the laboratory data, the threshold for effects with *N. incisa* appears to be greater than 200 mg/l suspended BRH suspended sediment, which was the highest concentration tested. Previous studies have also demonstrated that this species can tolerate bedded sediment concentrations in excess of 50-percent sediment without noted adverse effects. Consequently, effects were not expected from field exposures of similar intensity. Field exposures, estimated from tissue residue and chemical data, indicated that *N. incisa* experienced exposures to BRH suspended solids concentrations of 133 mg/l (Table 20) and bedded sediment concentrations as high as 44-percent BRH sediment (Table 19). These concentrations would not be expected to produce any adverse histological changes based upon laboratory data.

Laboratory-Field Comparisons

139. A primary objective of the FVP program is to field verify the laboratory biological responses by measuring the same response under both laboratory and field exposures. A basic and often implicit assumption is that results derived from laboratory tests are directly applicable in the field. To test this assumption, the exposure-response relationships between the laboratory and field must be compared. To determine whether the biological responses are responding to comparable situations in the laboratory and field, exposure conditions must be quantified and compared.

Mytilus edulis

140. Estimates of the exposure environment for *M. edulis* deployed at the FVP stations were made indirectly, by comparing tissue residue data between the laboratory and field, and from physical models. The first method used to estimate exposure conditions of *M. edulis* to BRH sediment in CLIS

involved the laboratory-generated relationships between PCB tissue residues and BRH exposures. With this relationship, PCB tissue residues in field-collected *M. edulis* were used to estimate field BRH exposure concentrations.

141. Comparisons of the laboratory and field exposure conditions using both tissue residue data and BRH suspended sediment concentrations from physical data indicate the following: (a) Cluster analysis of tissue residue data revealed that, with the exception of the period during and immediately after disposal, the field tissue residue values were similar to the laboratory reference tissue residues and predisposal field residues. (b) During disposal operations, the residue values were elevated and approached one-half of the values for the lowest laboratory exposure tissue residues.

142. The exposure estimates from the physical data indicate that the maximum field exposures also occurred during and immediately postdisposal. The maximum estimated BRH suspended sediment concentration estimated from chemical data was 1.30 to 1.05 mg/l from copper and PCB, respectively, which is similar to the lowest exposure concentration tested in the laboratory (1.5 mg/l). Laboratory exposures as BRH suspended sediment ranged from a low of 1.5 mg/l with an 80-percent incidence of gill pathology, and 3.3 mg/l with a 100-percent incidence of gill pathology plus pathology of the female reproductive tract and the kidney.

143. The laboratory data indicate that the histopathological response threshold occurred at BRH suspended sediment concentrations that were higher than the BRH exposure concentrations estimated to have occurred in the field. Based upon the laboratory dose response data, one would predict that there would be no histopathological effects for *M. edulis* exposed in the field, and that is in fact what happened. From that perspective, the laboratory to field comparison showed excellent agreement.

Nephtys incisa

144. To determine whether the biological responses are responding to comparable situations in the laboratory and the field, the exposure conditions must be determined and compared. Calculations based upon physical data were used to make different estimates of exposure to BRH material at the FVP stations. Assuming a 10 \times enrichment from the 1 m above the bottom to the bottom, sediment-water interface values of 0 to 12 mg BRH/l were calculated at the FVP stations as a result of disposal at the FVP site. Estimates of exposure via resuspension of surficial sediments predict much higher concentrations. A

maximum upper bound estimate assumes that all of the suspended solids are BRH material from the disposal mound. This calculation predicts up to 100 mg BRH/l under quiescent conditions and up to 300 mg BRH/l under storm conditions. A more probable model assumes that resuspended surficial sediments are the source of contaminants for the suspended solids. This model predicts a graded exposure at the FVP stations with maximum values of 40 mg/l at 200E, 12 mg/l at 400E, and 4 mg/l at 1000E for quiescent conditions. These values increase to 120 mg/l at 200E, 40 mg/l at 400E, and 10 mg/l at 1000E for storm conditions.

145. If it is assumed that tissue concentrations in *N. incisa* are directly related to exposure concentrations, this relationship may be used to test the reasonableness of the exposure model predictions. This assumption is reasonable, based on results from laboratory experiments. A cluster analysis of all *N. incisa* tissue residue data revealed no consistent clustering of the laboratory data separate from the field data. Any apparent clusters included both laboratory and field data. Therefore, if it is assumed that tissue concentrations reflect exposure concentrations, then this lack of association in the tissue concentration data indicates an overlap of laboratory exposure conditions with field exposure conditions. The estimates of field exposures to BRH sediment (milligrams per litre) suspended at the sediment-water interface based on PCB concentrations in field-collected *N. incisa* are up to 12 at REFS, 88 at 1000E, and 130 at 400E.

146. Field exposures were probably due to a combination of initial dispersion of BRH sediments during disposal and subsequent resuspension and movement of sediments from the dredged material mound. This results in calculated exposures of at least 10 mg/l at all FVP stations during disposal activities in CLIS and a maximum exposure estimate of up to 100 mg/l in the vicinity of the disposal mound. These estimates (10 to 100 mg/l) agree well with those predicted by the tissue concentration/exposure concentration relationship (12 to 130 mg/l). The laboratory exposures for the histopathology response were 0 and 200 mg BRH/l as suspended solids. These exposures overlap the estimated range of exposures in the field and simulated clean control conditions at REFS and worst-case storm conditions near the disposal mound.

147. The laboratory data indicate that the histopathological response threshold for *N. incisa* is above 200-mg/l BRH suspended sediment. The BRH suspended sediment concentrations at the sediment-water interface estimated

from the physical model and tissue residues ranged between 10 and 138 mg/ℓ. The laboratory studies showed that there were no histopathologies at exposures up to 200 mg/ℓ. Therefore, one would predict that the exposures to *N. incisa* in the field would not produce any histopathological effects. This is, in fact, what was observed, indicating that the laboratory and field results were in agreement.

Residue-Effect Relationships

Mytilus edulis

148. There was a strong link between exposure to BRH sediment and subsequent tissue residues in *M. edulis*, as confirmed by the data collected during the laboratory experiments. The relationship between mussel tissue residues for stable, high molecular weight compounds, PCBs in particular, tracked the BRH exposure concentrations remarkably well. For example, tissue residue data indicated that mussels from the 30-percent BRH exposure (3.3 mg/ℓ) exhibited twice the level of PCBs as those in the 10-percent BRH exposure (1.5 mg/ℓ). These data indicate that PCBs were a good "marker" for exposure to BRH material. Because of this relationship, residue concentrations of PCB can be assumed to be indicative of exposure concentration for BRH sediments. This relationship is particularly important in the field, where direct, continuous monitoring data of exposure conditions are difficult, if not impossible, to collect.

149. The histopathology data for *M. edulis* exposed in the laboratory (Tables 12 and 13) illustrate the relationship between exposure to BRH sediment and the incidence of pathology. Since there is a positive correlation between BRH sediment concentration and contaminant tissue residues (except for phenanthrene, cadmium, and chromium), it follows that observed incidences of histological changes also correlate with those contaminants forming tissue residues. The residue-effect relationship illustrated for PCB (Figure 43) can be visualized readily for other contaminants. It is important to note that such correlations are not to be interpreted as implying cause/effect.

150. There were no residue-effect relationships determined for *M. edulis* in the field due to the absence of observed histopathological effects. This is not unexpected since the mussel residues in the field were most similar to those from laboratory exposures with REF sediment and not BRH

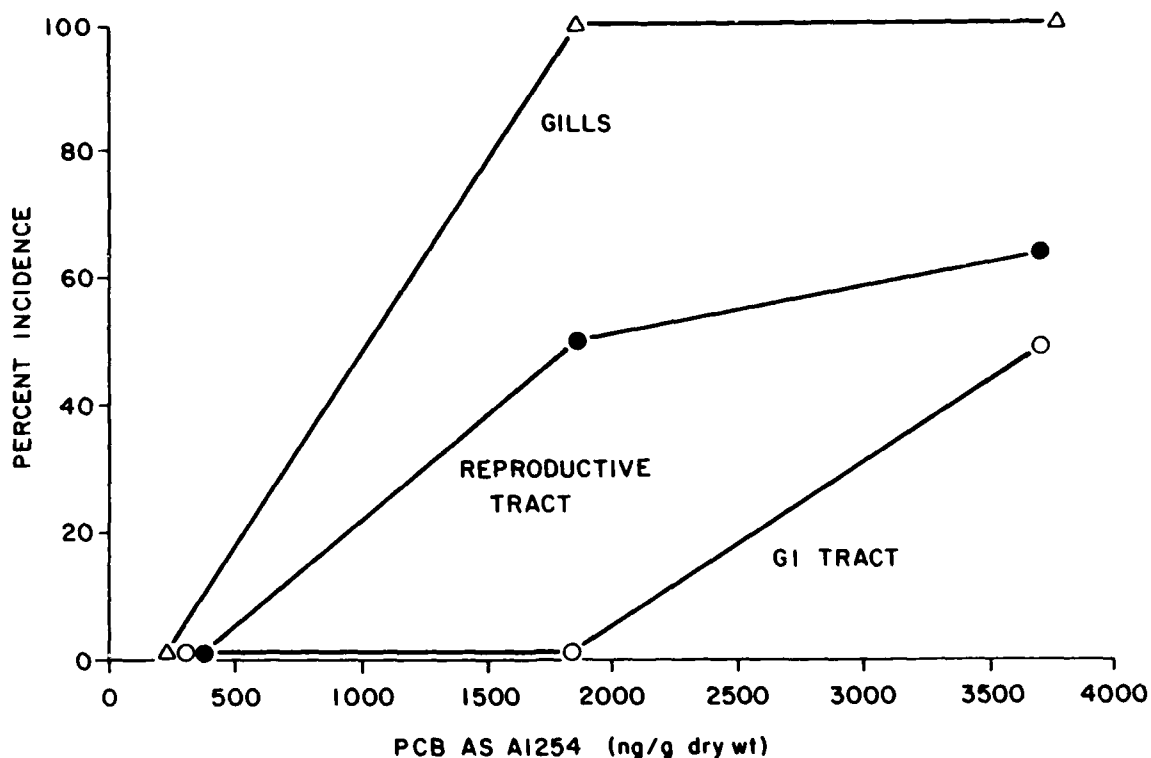


Figure 43. The relationship between PCB tissue residues and histopathological effects in laboratory exposed *M. edulis*

sediment. These results suggest that the absence of pathological effects in the field is a direct result of the duration and intensity of field exposures being below the response threshold for *M. edulis*. This is corroborated by the lack of significant elevations in contaminant tissue residues.

Nephtys incisa

151. The histopathological changes found in the worms appear to be of minor importance (compared with the impact upon major organ systems) and occurred only in individuals exposed in the laboratory. No histopathology was noted in specimens collected at the BRH disposal site. Tissue residue values occurring in worms from both the disposal site and laboratory studies were similar, indicating analogous exposures. This is supported by the cluster analysis. Therefore, there is no basis for presuming a relationship between tissue residues and histopathological changes in *N. incisa* exposed to BRH sediment.

PART V: CONCLUSIONS

152. The research described in this report evaluated the effects of dredged material on the histopathological responses of two aquatic species, the mussel *Mytilus edulis* and the polychaete *Nephtys incisa*. The results are summarized as follows:

- a. Laboratory dosing and exposure systems were developed to expose *M. edulis* and *N. incisa* to constant concentrations of suspended dredged material for up to 2 months.
- b. There was a direct relationship between BRH suspended sediment exposure, the tissue residue concentrations of PCBs, and the higher molecular weight PAHs and the incidence of histological responses in both species when they occurred.
- c. Histopathological changes in *M. edulis* were reported for the female reproductive tract, the gills, gastrointestinal tract, and kidney in the laboratory.
- d. Histopathological changes were not evident in *N. incisa* exposed in the laboratory. Thickening and darkening of the parapodial epidermis were evident in *N. incisa* but were not considered pathological.
- e. Independent estimates of field BRH concentrations, from tissue residues and water chemistry, indicated that maximum exposure to mussels occurred during the disposal operation and decreased rapidly thereafter. The maximum BRH sediment concentration estimated in the field was approximately 1.05 to 1.30 mg/l, which was similar to the lowest concentration tested in the laboratory (1.5 mg/l).
- f. Estimates of BRH concentrations at the sediment-water interface indicated that field exposures ranged from 10 to 100 mg/l based on data from physical models and 12 to 130 mg/l from tissue residues. These values are included within the 0 to 200 range used in laboratory studies.
- g. When coupled with exposure, laboratory-field comparisons showed remarkable and predictable agreement for both species. Using the exposure-response relationships developed in the laboratory and the exposures estimated for the field, predictions of field responses were consistently verified. Thus, when exposures were analogous in the lab and the field, the biological responses concurred.
- h. Residue-effect relationships were developed for *M. edulis* in the laboratory. Similar relationships could not be determined for field data because the exposures and resultant tissue residues were similar to background, and thus no histopathological effects were detected.
- i. Residue-effect relationships were not developed in the laboratory or field for *N. incisa* because the range of exposure

conditions in both cases was below the threshold for pathological effects in this species. Therefore, there is no basis for presuming a relationship between tissue residues and histopathological changes in *N. incisa* exposed to BRH sediment.

REFERENCES

- American Society for Testing and Materials (ASTM). 1980. "Standard Practice for Conducting Acute Toxicity Tests with Fishes, Macroinvertebrates, and Amphibians," ASTM E-729-80, Philadelphia, Pa.
- Bang, F. 1980. "Monitoring Pathological Changes As They Occur in the Estuaries and in the Ocean in Order to Measure Pollution," Rapports et Procès-Verbaux des Reunions, Conseil International pour l'Exploration de la Mer, Vol 179, pp 118-124.
- Bohlen, W. F., and Winnick, K. B. 1986. "Observations of Near-Bottom Suspended Material Concentrations at the FVP Site, Central Long Island Sound Dredged Materials Area: Immediate Predisposal, Disposal and Immediate Post-disposal Period, April 18, 1983-June 29, 1983," prepared for Science Applications International Corporation, Newport, R. I., by Marine Sciences Institute, Groton, Conn.
- Boyle, E. A., and Edmond, J. M. 1975. "Determination of Trace Metals in an Aqueous Solution by APDC Chelate Coprecipitation," in Analytical Methods in Oceanography, American Chemical Society Publication, Washington, DC, pp 44-55.
- Brown. 1980. "The Value of a Multidisciplinary Approach to Research on Marine Pollution Effects As Evidenced in a Three-Year Study to Determine the Etiology and Pathogenesis of Neoplasia in the Soft-Shell Clam, *Mya arenaria*," Rapport et Process - Verbaux des Reunions, Conseil International pour l'Exploration de la mer, Vol 179, pp 125-128.
- Gardner, G. R., and Yevich, P. P. 1970. "Histological and Hematological Responses of an Estuarine Teleost to Cadmium," Journal of Fisheries Research Board of Canada, Vol 27, pp 2185-2196.
- Gentile, J. H., and Scott, K. J. 1986. "The Application of a Hazard Assessment Strategy to Sediment Testing: Issues and Case Study," Fate and Effects of Sediment-Bound Chemicals in Aquatic Systems, K. L. Dickson, A. W. Maki, and W. Brungs, eds., SETAC Special Publication, Pergamon Press, N. Y., pp 1-17.
- Haensly, W., et al. 1982. "Histopathology of *Pleuronectes platessa* from Aber Wrack and Aber Benoit, Brittany, France: Long-Term Effects of the *Amoco Cadiz* Crude Oil Spill," Journal of Fish Disease, Vol 5, pp 365-391.
- Lake, J., Hoffman, G., and Schimmel, S. 1985. "The Bioaccumulation of Contaminants from Black Rock Harbor Dredged Material by Mussels and Polychaetes," Technical Report D-85-2, prepared by the US Environmental Protection Agency, Narragansett, R. I., for the US Army Engineer Waterways Experiment Station, Vicksburg, Miss.
- Munns, W. R., et al. 1986. "Exposure Assessment Component of the Field Verification Program: Data Presentation and Synthesis," Contribution 751, US Environmental Protection Agency, Environmental Research Laboratory, Narragansett, R. I.
- National Academy of Sciences. 1980. The International Mussel Watch, Appendix 6-B, Washington, DC.

Nelson, W. G., et al. 1987. "Effect of Black Rock Harbor Dredged Material on the Scope for Growth of the Blue Mussel *Mytilus edulis* After Laboratory and Field Exposures," Technical Report D-87-7, prepared by the US Environmental Protection Agency, Narragansett, R. I., for the US Army Engineer Waterways Experiment Station, Vicksburg, Miss.

Peters, E., et al. 1981. "Bioaccumulation and Histopathological Effects of Oil on a Stony Canal," *Marine Pollution Bulletin*, Vol 12, pp 333-339.

Phelps, D. K., and Galloway, W. B. 1980. "A Report on the Coastal Environmental Assessment Stations (CEAS) Program," Rapport et Process - Verbaux des Reunions, Conseil International pour l'Exploration de la Mer, Vol 179, pp 76-81.

Rogerson, P. F., Schimmel, S. C., and Hoffman, G. L. 1985. "Chemical and Biological Characterization of Black Rock Harbor Dredged Material," Technical Report D-85-9, US Army Engineer Waterways Experiment Station, Vicksburg, Miss.

SAS Institute, Inc. 1985. User's Guide: Statistics. Version 5, Gary, N. C.

Sindermann, C. 1979. "Pollution-Associated Diseases and Abnormalities of Fish and Shellfish: A Review," *Fishery Bulletin*, Vol 76, pp 717-750.

_____. 1980. "The Use of Pathological Effects of Pollutants in Marine Environmental Monitoring Programs," Rapports et Proces-Verbaux des Reunions, Conseil International pour l'Exploration de la Mer, Vol 179, pp 129-134.

Sinnett, J. C., and Davis, W. R. 1983. "A Programmable Turbidistat for Suspended Particles in Laboratory Aquaria," *Journal of Experimental Marine Biology and Ecology*, Vol 73, pp 167-174.

Snedecor, G. W., and Cochran, W. G. 1980. Statistical Methods, 7th ed. The Iowa State University Press, Ames, Iowa.

US Environmental Protection Agency (USEPA). 1979. "Methods for Chemical Analysis of Water and Wastes," EPA-600/4-79-020, Environmental Monitoring and Support Laboratory, Cincinnati, Ohio.

US Environmental Protection Agency/US Army Corps of Engineers (USEPA/CE). 1977. "Ecological Evaluation of Proposed Discharge of Dredged Material into Ocean Waters; Implementation Manual for Section 103 of PL 92-532," Environmental Effects Laboratory, US Army Engineer Waterways Experiment Station, Vicksburg, Miss.

Yevich, P. P., and Barszcz, C. A. 1977. "Neoplasia in Soft-Shell Clams, *Mya arenaria* Collected from Oil-Impacted Sites," Annals of New York Academy of Science, Vol 198, pp 414-426.

_____. 1981. "Preparation of Aquatic Animals for Histopathological Examination, Biological Field and Laboratory Methods for Measuring the Quality of Surface Waters and Wastes," 2d ed., preparation manual printed separately by the Aquatic Biology Section, Biological Methods Branch, Environmental Monitoring and Support Laboratory, US Environmental Protection Agency, Cincinnati, Ohio.

Yevich, P. P., et al. 1986. "The Histological Effects of Black Rock Harbor Dredged Material on Marine Organisms: A Laboratory Investigation," Technical Report D-86-1, prepared by the US Environmental Protection Agency, Narragansett, R. I., for the US Army Engineer Waterways Experiment Station, Vicksburg, Miss.

APPENDIX A: CHEMICAL FORMULAS, FIELD MUSSEL RESIDUE,
AND WORM RESIDUE CONCENTRATIONS

Table A1
Chemical Contaminants Selected for Measurement
in Both Field and Laboratory Studies

Chlorinated hydrocarbon pesticides

Polychlorinated biphenyls
 Ethylan

Aromatic hydrocarbons \geq molecular weight 166

<u>Compound Class</u>	<u>Molecular Weight</u>
Fluorene	166
C-1* Fluorene	180
C-2* Fluorene	194
C-3* Fluorene	208
C-4* Fluorene	222
Phenanthrene	178
Anthracene	178
C-1*Phenanthrene/anthracene	192
C-2*Phenanthrene/anthracene	206
C-3*Phenanthrene/anthracene	220
C-4*Phenanthrene/anthracene	234
Fluoranthene	202
Pyrene	202
C-1*Fluoranthene/pyrene	216
C-2*Fluoranthene/pyrene	230
C-3*Fluoranthene/pyrene	244
C-4*Fluoranthene/pyrene	258
Benzanthracene/chrysene**	228
C-1*Benzanthracene/chrysene**	242
C-2*Benzanthracene/chrysene**	256
C-3*Benzanthracene/chrysene**	270
C-4*Benzanthracene/chrysene**	284
Benzofluoranthenes	252
Benzo(e)pyrene	252
Benzo(a)pyrene	252
Perylene	252

(Continued)

* C-1, C-2, C-3, and C-4 refer to the number of methyl groups substituted somewhere in the parent compound.

** These names are representative of the class of polynuclear aromatic hydrocarbons (PAHs) measured at each molecular weight.

Table A1 (Concluded)

Compound Class	Molecular Weight
C-1*Benzopyrene/perylene**	266
C-2*Benzopyrene/perylene**	280
C-3*Benzopyrene/peryene**	294
C-4*Benzopyrene/peryene**	308
Benzoperylene**	376
Dibenzanthracene**	278
Coronene	300
Dibenzocrysene**	302
Hetrocyclic aromatic compounds	
Dibenzothiophene	184
C-1*dibenzothiophene	198
C-2*dibenzothiophene	212
C-3*dibenzothiophene	226
C-4*dibenzothiophene	240
Metals	
Cadmium	
Copper	
Chromium	
Iron	
Lead	
Manganese	
Nickel	
Zinc	

* C-1, C-2, C-3, and C-4 refer to the number of methyl groups substituted somewhere in the parent compound.

** These names are representative of the class of polynuclear aromatic hydrocarbons (PAHs) measured at each molecular weight.

Table A2

Complete Formulae for Calculating all SUM and CENT Variables

$$\begin{aligned}
 \text{PSUM} &= \text{POS166} + \text{POS178} + \text{POS202} + \text{POS228} + \text{POS252} + \text{POS276} + \text{POS278} + \\
 &\quad \text{POS300} + \text{POS302} \\
 \text{HSUM} &= \text{H1C166} + \text{H2C166} + \text{H3C166} + \text{H4C166} + \text{H1C178} + \text{H2C178} + \text{H3C178} + \\
 &\quad \text{H4C178} + \text{H1C202} + \text{H2C202} + \text{H3C202} + \text{H4C202} + \text{H1C228} + \text{H2C228} + \\
 &\quad \text{H3C228} + \text{H4C228} + \text{H1C252} + \text{H2C252} + \text{H3C252} + \text{H4C252} \\
 \text{SUM} &= \text{POS166} + \text{H1C166} + \text{H2C166} + \text{H3C166} + \text{H4C166} + \text{POS178} + \text{H1C178} + \\
 &\quad \text{H2C178} + \text{H3C178} + \text{H4C178} + \text{POS202} + \text{H1C202} + \text{H2C202} + \text{H3C202} + \\
 &\quad \text{H4C202} + \text{POS228} + \text{H1C228} + \text{H2C228} + \text{H3C228} + \text{H4C228} + \text{POS252} + \\
 &\quad \text{H1C252} + \text{H2C252} + \text{H3C252} + \text{H4C252} + \text{POS276} + \text{POS278} + \text{POS300} + \\
 &\quad \text{POS302} \\
 \text{PCENT} &= [\text{POS166} \cdot 166 + \text{POS178} \cdot 178 + \text{POS202} \cdot 202 + \text{POS228} \cdot 228 + \text{POS252} \cdot 252 + \\
 &\quad \text{POS276} \cdot 276 + \text{POS278} \cdot 278 + \text{POS300} \cdot 300 + \text{POS302} \cdot 302] / \text{PSUM} \\
 \text{HCENT} &= [\text{H1C166} \cdot 180 + \text{H2C166} \cdot 194 + \text{H3C166} \cdot 208 + \text{H4C166} \cdot 222 + \text{H1C178} \cdot 192 + \\
 &\quad \text{H2C178} \cdot 206 + \text{H3C178} \cdot 220 + \text{H4C178} \cdot 234 + \text{H1C202} \cdot 216 + \text{H2C202} \cdot 230 + \\
 &\quad \text{H3C202} \cdot 244 + \text{H4C202} \cdot 258 + \text{H1C228} \cdot 242 + \text{H2C228} \cdot 256 + \text{H3C228} \cdot 270 + \\
 &\quad \text{H4C228} \cdot 284 + \text{H1C252} \cdot 266 + \text{H2C252} \cdot 280 + \text{H3C252} \cdot 294 + \text{H4C252} \cdot 308] / \\
 &\quad \text{HSUM} \\
 \text{CENT} &= [\text{POS166} \cdot 166 + \text{H1C166} \cdot 180 + \text{H2C166} \cdot 194 + \text{H3C166} \cdot 208 + \text{H4C166} \cdot 222 + \\
 &\quad \text{POS178} \cdot 178 + \text{H1C178} \cdot 192 + \text{H2C178} \cdot 206 + \text{H3C178} \cdot 220 + \text{H4C178} \cdot 234 + \\
 &\quad \text{POS202} \cdot 202 + \text{H1C202} \cdot 216 + \text{H2C202} \cdot 230 + \text{H3C202} \cdot 244 + \text{H4C202} \cdot 258 + \\
 &\quad \text{POS228} \cdot 228 + \text{H1C228} \cdot 242 + \text{H2C228} \cdot 256 + \text{H3C228} \cdot 270 + \text{H4C228} \cdot 284 + \\
 &\quad \text{POS252} \cdot 252 + \text{H1C252} \cdot 266 + \text{H2C252} \cdot 280 + \text{H3C252} \cdot 294 + \text{H4C252} \cdot 308 + \\
 &\quad \text{POS276} \cdot 276 + \text{POS278} \cdot 278 + \text{POS300} \cdot 300 + \text{POS302} \cdot 302] / \text{SUM}
 \end{aligned}$$

The sum of alkyl homologs of PAH molecular weight 178 (HOS178) is calculated according to the following formula:

$$\text{HOS178} = \text{H1C178} + \text{H2C178} + \text{H3C178} + \text{H4C178}$$

where

$$\text{HOS178} = \text{sum of C-1 to C-4 alkyl-substituted 178 PAHs}$$

This statistic was chosen to describe the alkyl homologs because the 178 alkyl homologs are the most intense homologs within the Black Rock Harbor (BRH) PAH distribution and because they afford the greatest BRH to REFS concentration ratio. Alkyl homologs were included because of potential differences between them and parent PAHs.

Table A3
Tissue Residue Concentrations in Mussels from the
T - 4 Field Collection in CLIS (22 Apr 83)*

<u>Chemical Compound</u>	<u>Station</u>			
	<u>CNTR</u>	<u>400E</u>	<u>1000E</u>	<u>REFS</u>
Phenanthrene	210.0	117.0	98.0	38.0
Sum of 178 alkyl homologs	580.0	310.0	310.0	290.0
Fluoranthene	161.0	102.0	90.0	82.0
Benzo(a)pyrene	37.0	20.0	34.0	25.0
Ethylan	5.0	3.0	5.0	10.0
PCB as A1254	380.0	270.0	400.0	440.0
SUM of PAHs	2,600.0	1,520.0	1,650.0	1,380.0
Centroid of PAHs	218.0	219.0	225.0	228.0
Copper	13.5	15.1	14.5	12.5
Cadmium	1.9	1.8	1.8	1.8
Chromium	1.8	3.8	2.2	1.6
Iron	370.0	1,400.0	530.0	340.0

* Units are nanograms per gram dry weight for the organic compounds and the statistic SUM, micrograms per gram dry weight for the inorganic elements, and molecular weight for the statistic centroid.

Table A4

Tissue Residue Concentrations in Mussels from the T + 0 Field Collection in
CLIS (24 May 83).* The CNTR Station Was Not Deployed Because of
the Dumping Operation, and the 400E Station Was Lost

Chemical Compound	Station	
	1000E	REFS
Phenanthrene	43.0	16.0
Sum of 178 alkyl homologs	1,440.0	290.0
Fluoranthene	161.0	52.0
Benzo(a)pyrene	100.0	18.0
Ethylan	102.0	9.0
PCB as A1254	1,080.0	500.0
SUM of PAHs	5,400.0	1,290.0
Centroid of PAHs	230.0	232.0
Copper	16.5	10.9
Cadmium	2.0	2.3
Chromium	2.6	1.5
Iron	420.0	330.0

* Units are nanograms per gram dry weight for the organic compounds and the statistic SUM, micrograms per gram dry weight for the inorganic elements, and molecular weight for the statistic centroid.

Table A5
Tissue Residue Concentrations in Mussels from the T + 2 Field Collection in
CLIS (07 June 83).* The CNTR Station Was Not Deployed Because
of the Disposal Operation

<u>Chemical Compound</u>	<u>Station</u>		
	<u>400E</u>	<u>1000E</u>	<u>REFS</u>
Phenanthrene	69.0	41.0	13.0
Sum of 178 alkyl homologs	1,900.0	970.0	540.0
Fluoranthene	290.0	126.0	72.0
Benzo(a)pyrene	210.0	118.0	51.0
Ethylan	71.0	39.0	17.0
PCB as A1254	1,440.0	1,020.0	630.0
SUM of PAHs	8,700.0	4,700.0	2,500.0
Centroid of PAHs	232.0	234.0	233.0
Copper	16.9	15.6	10.8
Cadmium	2.3	2.3	1.9
Chromium	3.0	3.0	2.0
Iron	510.0	560.0	560.0

* Units are nanograms per gram dry weight for the organic compounds and the statistic SUM, micrograms per gram dry weight for the inorganic elements, and molecular weight for the statistic centroid.

Table A6
Tissue Residue Concentrations in Mussels from the
T + 8 Field Collection in CLIS (10 Jul 83)*

<u>Chemical Compound</u>	<u>Station</u>			
	<u>CNTR</u>	<u>400E</u>	<u>1000E</u>	<u>REFS</u>
Phenanthrene	11.0	14.0	9.0	7.0
Sum of 178 alkyl homologs	350.0	340.0	193.0	105.0
Fluoranthene	45.0	46.0	31.0	23.0
Benzo(a)pyrene	40.0	50.0	18.0	20.0
Ethylan	22.0	20.0	7.0	1.0
PCB as A1254	700.0	740.0	620.0	480.0
SUM of PAHs	1,870.0	2,100.0	1,020.0	760.0
Centroid of PAHs	234.0	236.0	231.0	240.0
Copper	10.1	9.6	11.5	4.4
Cadmium	1.9	2.0	1.3	0.9
Chromium	1.4	1.4	3.2	0.8
Iron	340.0	370.0	820.0	240.0

* Units are nanograms per gram dry weight for the organic compounds and the statistic SUM, micrograms per gram dry weight for the inorganic elements, and molecular weight for the statistic centroid.

Table A7
Tissue Residue Concentrations in Mussels from the
T + 12 Field Collection in CLIS (10 Aug 83)*

Chemical Compound	Station			
	CNTR	400E	1000E	REFS
Phenanthrene	17.0	10.0	9.0	8.0
Sum of 178 alkyl homologs	250.0	160.0	96.0	65.0
Fluoranthene	41.0	28.0	20.0	15.0
Benzo(a)pyrene	41.0	17.0	16.0	13.0
Ethylan	9.0	8.0	3.0	1.0
PCB as A1254	640.0	660.0	550.0	570.0
SUM of PAHs	1,600.0	940.0	710.0	530.0
Centroid of PAHs	237.0	236.0	239.0	240.0
Copper	5.3	5.6	7.5	5.8
Cadmium	0.9	0.9	1.2	1.1
Chromium	1.0	0.7	1.6	0.7
Iron	164.0	167.0	450.0	177.0

* Units are nanograms per gram dry weight for the organic compounds and the statistic SUM, micrograms per gram dry weight for the inorganic elements, and molecular weight for the statistic centroid.

Table A8
Tissue Residue Concentrations in Mussels from the
T + 15 Field Collection in CLIS (06 Sep 83)*

Chemical Compound	Station			
	CNTR	400E	1000E	REFS
Phenanthrene	13.0	9.0	10.0	6.0
Sum of 178 alkyl homologs	370.0	230.0	210.0	43.0
Fluoranthene	57.0	38.0	33.0	14.0
Benzo(a)pyrene	53.0	45.0	28.0	7.0
Ethylan	10.0	6.0	4.0	1.0
PCB as A1254	870.0	630.0	640.0	550.0
SUM of PAHs	2,100.0	1,540.0	1,240.0	350.0
Centroid of PAHs	236.0	239.0	237.0	238.0
Copper	7.7	6.0	8.0	5.8
Cadmium	1.0	1.1	1.1	0.9
Chromium	1.2	0.9	1.1	0.9
Iron	260.0	179.0	290.0	260.0

* Units are nanograms per gram dry weight for the organic compounds and the statistic SUM, micrograms per gram dry weight for the inorganic elements, and molecular weight for the statistic centroid.

Table A9
Tissue Residue Concentrations in Mussels from the
T + 21 Field Collection in CLIS (18 Oct 83)*

Chemical Compound	Station			
	CNTR	400E	1000E	REFS
Phenanthrene	12.0	11.0	11.0	10.0
Sum of 178 alkyl homologs	132.0	101.0	88.0	46.0
Fluoranthene	33.0	25.0	22.0	16.0
Benzo(a)pyrene	24.0	9.0	17.0	9.0
Ethylan	2.0	2.0	1.0	0.0
PCB as A1254	540.0	680.0	570.0	420.0
SUM of PAHs	1,000.0	670.0	700.0	400.0
Centroid of PAHs	240.0	234.0	239.0	238.0
Copper	22.1	16.3	15.1	16.4
Cadmium	5.1	4.4	4.8	5.0
Chromium	2.3	2.6	2.2	2.2
Iron	440.0	540.0	420.0	480.0

* Units are nanograms per gram dry weight for the organic compounds and the statistic SUM, micrograms per gram dry weight for the inorganic elements, and molecular weight for the statistic centroid.

Table A10
Tissue Residue Concentrations in Mussels from the T + 27 Field Collection in
CLIS (29 Nov 83).* The CNTR Station Was Missing
at the Time of Collection

<u>Chemical Compound</u>	<u>Station</u>		<u>REFS</u>
	<u>400E</u>	<u>1000E</u>	
Phenanthrene	18.0	10.0	8.0
Sum of 178 alkyl homologs	230.0	117.0	86.0
Fluoranthene	68.0	36.0	37.0
Benzo(a)pyrene	39.0	32.0	19.0
Ethylan	3.0	1.0	0.0
PCB as A1254	540.0	380.0	450.0
SUM of PAHs	1,820.0	1,150.0	860.0
Centroid of PAHs	240.0	244.0	240.0
Copper	16.4	21.0	23.3
Cadmium	3.2	3.4	3.6
Chromium	2.5	3.6	3.3
Iron	570.0	920.0	920.0

* Units are nanograms per gram dry weight for the organic compounds and the statistic SUM, micrograms per gram dry weight for the inorganic elements, and molecular weight for the statistic centroid.

Table All

Tissue Residue Concentrations in Mussels from the T + 43 Field Collection in
CLIS (20 Mar 84). * Metals Were Not Measured for These Samples.

The 1000E Station Was Missing at the Time of Collection

<u>Chemical Compound</u>	<u>Station</u>		
	<u>CNTR</u>	<u>400E</u>	<u>REFS</u>
Phenanthrene	16	18	17
Sum of 178 alkyl homologs	94	78	70
Fluoranthene	28	26	24
Benzo(a)pyrene	8	4	7
Ethylan	2	1	1
PCB as A1254	350	330	280
SUM of PAHs	510	460	450
Centroid of PAHs	229	230	231

* Units are nanograms per gram dry weight for the organic compounds and the statistic SUM, and molecular weight for the statistic centroid.

Table A12

Tissue Residue Concentrations in Mussels from the T + 55 Field Collection in
CLIS (05 June 84). * Metals Were Not Measured in These Samples.

The CNTR Station Was Missing at the Time of Collection

<u>Chemical Compound</u>	<u>Station</u>		
	<u>400E</u>	<u>1000E</u>	<u>REFS</u>
Phenanthrene	6	6	4
Sum of 178 alkyl homologs	89	91	54
Fluoranthene	25	31	18
Benzo(a)pyrene	6	7	6
Ethylan	0	1	0
PCB as A1254	540	490	550
SUM of PAHs	520	550	370
Centroid of PAHs	234	235	236

* Units are nanograms per gram dry weight for the organic compounds and the statistic SUM, and molecular weight for the statistic centroid.

Table A13
Tissue Residue Concentrations in Mussels from the
T + 116 Field Collection in CLIS (13 Aug 85)*

Chemical Compound	Station			
	CNTR	400E	1000E	REFS
Phenanthrene	3.0	6.0	3.0	3.0
Sum of 178 alkyl homologs	79.0	124.0	80.0	58.0
Fluoranthene	18.0	27.0	24.0	19.0
Benzo(a)pyrene	18.0	40.0	22.0	17.0
Ethylan	1.0	2.0	1.0	0.0
PCB as A1254	310.0	350.0	450.0	440.0
SUM of PAHs	700.0	1,270.0	810.0	620.0
Centroid of PAHs	242.0	243.0	241.0	244.0
Copper	8.5	7.5	6.9	7.6
Cadmium	1.5	1.3	1.3	1.3
Chromium	1.2	1.1	0.9	0.9
Iron	290.0	260.0	220.0	220.0

* Units are nanograms per gram dry weight for the organic compounds and the statistic SUM, micrograms per gram dry weight for the inorganic elements, and molecular weight for the statistic centroid.

Table A14

Tissue Residue Concentrations in *N. incisa* from the T - 39 WeeksField Collection in CLIS (17 Aug 82)*

<u>Chemical Compound</u>	<u>Station</u>			
	<u>CNTR</u>	<u>400E</u>	<u>1000E</u>	<u>REFS</u>
Phenanthrene	--	--	--	--
Sum of 178 alkyl homologs	--	--	--	--
Fluoranthene	--	--	--	--
Benzo(a)pyrene	--	--	--	--
Ethylan	--	--	--	--
PCB as A1254	--	189	--	210
SUM of PAHs	--	--	--	--
Centroid of PAHs	--	--	--	--
Copper	--	--	--	--
Cadmium	--	--	--	--
Chromium	--	--	--	--
Iron	--	--	--	--

* Units are nanograms per gram dry weight for the organic compounds and the statistic SUM, micrograms per gram dry weight for the inorganic elements, and molecular weight for the statistic centroid.

Table A15

Tissue Residue Concentrations in *N. incisa* from the T - 26 WeeksField Collection in CLIS (16 Oct 82)*

Chemical Compound	Station			
	CNTR	400E	1000E	REFS
Phenanthrene	--	--	--	--
Sum of 178 alkyl homologs	--	--	--	--
Fluoranthene	--	--	--	--
Benzo(a)pyrene	--	--	--	--
Ethylan	--	--	--	--
PCB as A1254	--	240	--	290
SUM of PAHs	--	--	--	--
Centroid of PAHs	--	--	--	--
Copper	--	--	--	--
Cadmium	--	--	--	--
Chromium	--	--	--	--
Iron	--	--	--	--

* Units are nanograms per gram dry weight for the organic compounds and the statistic SUM, micrograms per gram dry weight for the inorganic elements, and molecular weight for the statistic centroid.

Table A16

Tissue Residue Concentrations in *N. incisa* from the T - 13 WeeksField Collection in CLIS (16 Feb 83)*

Chemical Compound	Station			
	CNTR	400E	1000E	REFS
Phenanthrene	--	5.6	--	4.0
Sum of 178 alkyl homologs	--	67.0	--	34.0
Fluoranthene	--	37.0	--	26.0
Benzo(a)pyrene	--	19.0	--	10.0
Ethylan	--	0.0	--	0.0
PCB as A1254	--	340.0	--	290.0
SUM of PAHs	--	780.0	--	530.0
Centroid of PAHs	--	242.9	--	244.4
Copper	--	18.1	--	21.0
Cadmium	--	0.1	--	0.5
Chromium	--	1.3	--	1.9
Iron	--	570.0	--	770.0

* Units are nanograms per gram dry weight for the organic compounds and the statistic SUM, micrograms per gram dry weight for the inorganic elements, and molecular weight for the statistic centroid.

Table A17

Tissue Residue Concentrations in *N. incisa* from the T - 11 Weels
Field Collection in CLIS (04 Mar 83)*

Chemical Compound	Station				
	CNTR	200E	400E	1000E	REFS
Phenanthrene	--	--	--	--	--
Sum of 178 alkyl homologs	--	--	--	--	--
Fluoranthene	--	--	--	--	--
Benzo(a)pyrene	--	--	--	--	--
Ethylan	--	--	--	--	--
PCB as A1254	--	--	--	--	--
SUM of PAHs	--	--	--	--	--
Centroid of PAHs	--	--	--	--	--
Copper	36.0	39.0	37.0	42.0	26.0
Cadmium	0.8	0.5	0.7	1.0	0.6
Chromium	2.9	1.7	1.7	2.4	2.0
Iron	980.0	790.0	760.0	980.0	1,040.0

* Units are nanograms per gram dry weight for the organic compounds and the statistic SUM, micrograms per gram dry weight for the inorganic elements, and molecular weight for the statistic centroid.

Table A18
Tissue Residue Concentrations in *N. incisa* from the T - 5 Weeks
Field Collection in CLIS (12 Mar 83)*

<u>Chemical Compound</u>	<u>Station</u>			
	<u>CNTR</u>	<u>400E</u>	<u>1000E</u>	<u>REFS</u>
Phenanthrene	--	10.7	--	9.6
Sum of 178 alkyl homologs	0	79.0	0	50.0
Fluoranthene	--	47.0	--	35.0
Benzo(a)pyrene	--	24.0	--	21.0
Ethylan	--	0.0	--	0.0
PCB as A1254	--	390.0	--	340.0
SUM of PAHs	--	960.0	--	710.0
Centroid of PAHs	--	241.4	--	243.7
Copper	--	49.0	--	28.0
Cadmium	--	0.5	--	0.6
Chromium	--	3.9	--	2.1
Iron	--	1,360.0	--	930.0

* Units are nanograms per gram dry weight for the organic compounds and the statistic SUM, micrograms per gram dry weight for the inorganic elements, and molecular weight for the statistic centroid.

Table A19

Tissue Residue Concentrations in *N. incisa* from the T + 2 WeeksField Collection in CLIS (02 Jun 83)*

Chemical Compound	Station			
	CNTR	400E	1000E	REFS
Phenanthrene	--	360.0	60.0	6.2
Sum of 178 alkyl homologs	--	3,690.0	840.0	44.0
Fluoranthene	--	970.0	197.0	19.0
Benzo(a)pyrene	--	250.0	85.0	13.0
Ethylan	--	0.0	0.0	0.0
PCB as A1254	--	1,060.0	630.0	290.0
SUM of PAHs	--	15,100.0	4,200.0	420.0
Centroid of PAHs	--	221.9	229.3	241.0
Copper	--	37.0	23.0	--
Cadmium	--	0.6	0.2	--
Chromium	--	1.1	1.2	--
Iron	--	670.0	680.0	--

* Units are nanograms per gram dry weight for the organic compounds and the statistic SUM, micrograms per gram dry weight for the inorganic elements, and molecular weight for the statistic centroid.

Table A20

Tissue Residue Concentrations in *N. incisa* from the T + 7 WeeksField Collection in CLIS (03 Jul 83)*

<u>Chemical Compound</u>	<u>Station</u>			
	<u>CNTR</u>	<u>400E</u>	<u>1000E</u>	<u>REFS</u>
Phenanthrene	--	300.0	8.3	7.8
Sum of 178 alkyl homologs	--	3,700.0	260.0	79.0
Fluoranthene	--	650.0	49.0	31.0
Benzo(a)pyrene	--	420.0	66.0	19.0
Ethylan	--	0.0	0.0	0.0
PCB as A1254	--	1,160.0	630.0	290.0
SUM of PAHs	--	16,700.0	1,980.0	840.0
Centroid of PAHs	--	229.5	241.4	243.3
Copper	--	--	--	--
Cadmium	--	--	--	--
Chromium	--	--	--	--
Iron	--	--	--	--

* Units are nanograms per gram dry weight for the organic compounds and the statistic SUM, micrograms per gram dry weight for the inorganic elements, and molecular weight for the statistic centroid.

Table A21

Tissue Residue Concentrations in *N. incisa* from the T + 8 Weeks

Field Collection in CLIS (13 Jul 83)*

Chemical Compound	Station			
	CNTR	400E	1000E	REFS
Phenanthrene	--	--	--	--
Sum of 178 alkyl homologs	--	--	--	--
Fluoranthene	--	--	--	--
Benzo(a)pyrene	--	--	--	--
Ethylan	--	--	--	--
PCB as A1254	--	--	--	--
SUM of PAHs	--	--	--	--
Centroid of PAHs	--	--	--	--
Copper	--	27.0	37.0	--
Cadmium	--	0.3	0.5	--
Chromium	--	3.2	1.9	--
Iron	--	520.0	690.0	--

* Units are nanograms per gram dry weight for the organic compounds and the statistic SUM, micrograms per gram dry weight for the inorganic elements, and molecular weight for the statistic centroid.

Table A22

Tissue Residue Concentrations in *N. incisa* from the T + 16 Weeks

Field Collection in CLIS (06 Sep 83)*

Chemical Compound	Station			
	CNTR	400E	1000E	REFS
Phenanthrene	--	14.3	9.8	7.3
Sum of 178 alkyl homologs	--	890.0	420.0	66.0
Fluoranthene	--	165.0	111.0	37.0
Benzo(a)pyrene	--	195.0	85.0	27.0
Ethylan	--	0.0	0.0	0.0
PCB as A1254	--	1,240.0	1,000.0	370.0
SUM of PAHs	--	5,900.0	2,900.0	850.0
Centroid of PAHs	--	239.0	239.4	243.8
Copper	--	27.0	37.0	26.0
Cadmium	--	0.2	0.4	0.5
Chromium	--	1.8	2.3	2.2
Iron	--	650.0	970.0	1,210.0

* Units are nanograms per gram dry weight for the organic compounds and the statistic SUM, micrograms per gram dry weight for the inorganic elements, and molecular weight for the statistic centroid.

Table A23

Tissue Residue Concentrations in *N. incisa* from the T + 28 Weeks
Field Collection in CLIS (29 Nov 83)*

Chemical Compound	Station			
	CNTR	400E	1000E	REFS
Phenanthrene	--	48.0	5.8	3.4
Sum of 178 alkyl homologs	--	870.0	93.0	34.0
Fluoranthene	--	210.0	36.0	23.0
Benzo(a)pyrene	--	122.0	35.0	16.0
Ethylan	--	0.0	0.0	0.0
PCB as A1254	--	690.0	480.0	240.0
SUM of PAHs	--	5,100.0	1,330.0	550.0
Centroid of PAHs	--	232.7	249.4	248.4
Copper	--	40.0	17.8	--
Cadmium	--	0.4	0.2	--
Chromium	--	1.8	1.4	--
Iron	--	790.0	530.0	--

* Units are nanograms per gram dry weight for the organic compounds and the statistic SUM, micrograms per gram dry weight for the inorganic elements, and molecular weight for the statistic centroid.

Table A24

Tissue Residue Concentrations in *N. incisa* from the T + 44 WeeksField Collection in CLIS (20 Mar 84)*

Chemical Compound	Station			
	CNTR	400E	1000E	REFS
Phenanthrene	220.0	4.4	4.6	1.5
Sum of 178 alkyl homologs	1,100.0	950.0	18.0	1.2
Fluoranthene	270.0	230.0	31.0	24.0
Benzo(a)pyrene	159.0	132.0	22.0	10.0
Ethylan	0.0	0.0	0.0	0.0
PCB as A1254	650.0	580.0	350.0	220.0
SUM of PAHs	4,900.0	4,300.0	380.0	183.0
Centroid of PAHs	221.2	224.7	235.0	233.1
Copper	--	--	--	--
Cadmium	--	--	--	--
Chromium	--	--	--	--
Iron	--	--	--	--

* Units are nanograms per gram dry weight for the organic compounds and the statistic SUM, micrograms per gram dry weight for the inorganic elements, and molecular weight for the statistic centroid.

Table A25

Tissue Residue Concentrations in *N. incisa* from the T + 56 WeeksField Collection in CLIS (13 Jun 84)*

<u>Chemical Compound</u>	<u>Station</u>			
	<u>CNTR</u>	<u>400E</u>	<u>1000E</u>	<u>REFS</u>
Phenanthrene	--	--	--	--
Sum of 178 alkyl homologs	--	--	--	--
Fluoranthene	--	--	--	--
Benzo(a)pyrene	--	--	--	--
Ethylan	--	--	--	--
PCB as A1254	--	--	--	--
SUM of PAHs	--	--	--	--
Centroid of PAHs	--	--	--	--
Copper	174.0	--	44.0	39.0
Cadmium	1.0	--	0.6	0.7
Chromium	5.9	--	2.1	1.9
Iron	380.0	--	680.0	770.0

* Units are nanograms per gram dry weight for the organic compounds and the statistic SUM, micrograms per gram dry weight for the inorganic elements, and molecular weight for the statistic centroid.

Table A26

Tissue Residue Concentrations in *N. incisa* from the T + 73 Weeks
Field Collection in CLIS (10 Oct 84)*

<u>Chemical Compound</u>	<u>Station</u>			<u>REFS</u>
	<u>CNTR</u>	<u>400E</u>	<u>1000E</u>	
Phenanthrene	--	--	--	--
Sum of 178 alkyl homologs	--	--	--	--
Fluoranthene	--	--	--	--
Benzo(a)pyrene	--	--	--	--
Ethylan	--	--	--	--
PCB as A1254	--	--	--	--
SUM of PAHs	--	--	--	--
Centroid of PAHs	--	--	--	--
Copper	50.0	44.0	47.0	28.0
Cadmium	1.6	1.2	2.3	1.3
Chromium	3.3	1.0	1.6	1.6
Iron	790.0	840.0	930.0	610.0

* Units are nanograms per gram dry weight for the organic compounds and the statistic SUM, micrograms per gram dry weight for the inorganic elements, and molecular weight for the statistic centroid.

Table A27

Tissue Residue Concentrations in *N. incisa* from the T + 74 Weeks
Field Collection in CLIS (16 Oct 84)*

<u>Chemical Compound</u>	<u>Station</u>			
	<u>CNTR</u>	<u>400E</u>	<u>1000E</u>	<u>REFS</u>
Phenanthrene	500.0	7.9	5.1	3.2
Sum of 178 alkyl homologs	4,800.0	200.0	124.0	33.0
Fluoranthene	1,410.0	96.0	57.0	27.0
Benzo(a)pyrene	102.0	40.0	46.0	19.0
Ethylan	13.6	0.0	0.0	0.0
PCB as A1254	710.0	510.0	350.0	300.0
SUM of PAHs	16,000.0	1,660.0	1,320.0	580.0
Centroid of PAHs	208.1	233.9	242.5	246.3
Copper	86.0	--	--	--
Cadmium	0.6	--	--	--
Chromium	2.5	--	--	--
Iron	680.0	--	--	--

* Units are nanograms per gram dry weight for the organic compounds and the statistic SUM, micrograms per gram dry weight for the inorganic elements, and molecular weight for the statistic centroid.

Table A28

Tissue Residue Concentrations in *N. incisa* from the T + 140 WeeksField Collection in CLIS (24 Jan 86)*

Chemical Compound	Station				
	CNTR	200E	400E	1000E	REFS
Phenanthrene	7.3	--	4.7	12.0	
Sum of 178 alkyl homologs	1,070.0	--	58.0	390.0	
Fluoranthene	300.0	--	23.0	78.0	27.0
Benzo(a)pyrene	162.0	--	21.0	91.0	23.0
Ethylan	6.2	--	0.0	0.0	0.0
PCB as A1254	900.0	--	310.0	300.0	160.0
SUM of PAHs	6,400.0	--	630.0	3,000.0	660.0
Centroid of PAHs	232.1	--	244.0	244.5	253.7
Copper	83.0	53.0	44.0	46.0	32.0
Cadmium	1.8	0.9	0.6	0.8	0.7
Chromium	9.9	4.3	2.4	2.0	2.1
Iron	840.0	970.0	1,250.0	920.0	970.0

* Units are nanograms per gram dry weight for the organic compounds and the statistic SUM, micrograms per gram dry weight for the inorganic elements, and molecular weight for the statistic centroid.

APPENDIX B: BLACK ROCK HARBOR (BRH) SEDIMENT PERCENTAGE CALCULATIONS
AND SURFICIAL CHEMISTRY DATA

Table B1
Percentage of Black Rock Harbor (BRH) Sediment in the Surficial Sediments (0-2 cm)
and the Contaminants Used for the Percent Calculations

Date	Station		
	CNTR	200E	400E 1000E
	<u>Percentage of BRH Sediment</u>		
Jun 83	44.5	41.1	12.5 1.8
Jul 83	15.0	37.4	3.3 1.6
Sep 83	32.0	36.7	4.9 2.0
Dec 83	32.8	36.1	9.5 4.4
Mar 84	4.4	2.2	1.9 1.8
Jun 84	9.5	15.6	0.5 0.7
Sep 84	10.0	0.8	3.5 0.5
Oct 84	2.6	--	0.2 1.6
Dec 84	35.1	11.3	0.0 1.0
Oct 85	1.2	11.0	0.0 0.0

Continued

Table B1 (Concluded)

Date	Station			
	CNTR	200E	400E	1000E
		<u>Contaminants Used</u>		
Aug 83	PAH+PCB+Cd+Cu+Cr	PAH+PCB+Cd+Cu+Cr	PAH+PCB+Cd+Cu+Cr	Cd+Cu+Cr
Jul 83	PAH+Cd+Cu+Cr	PAH+PCB+Cd+Cu+Cr	PAH+PCB+Cd+Cr	PAH+PCB+Cd+Cu+Cr
Jul 83	PAH+PCB+Cd+Cu+Cr	PAH+PCB+Cd+Cu+Cr	PAH+PCB+Cd+Cu+Cr	PAH+PCB+Cd+Cu+Cr
Jul 83	Cd+Cu+Cr	Cd+Cu+Cr	Cd+Cu+Cr	Cd+Cu+Cr
May 83	PAH+PCB+Cd+Cu+Cr	PAH+PCB+Cd+Cu+Cr	PAH+PCB+Cd+Cu+Cr	PAH+PCB+Cu+Cr
Apr 83	Cd+Cu+Cr	Cd+Cu+Cr	Cd+Cu+Cr	Cu+Cr
Apr 83	PAH+PCB+Cd+Cu+Cr	PAH+PCB+Cd+Cu+Cr	PAH+PCB+Cu+Cr	PAH+PCB+Cu+Cr
Apr 83	PAH+PCB	--	PAH+PCB	PAH+PCB
Dec 82	Cd+Cu+Cr	Cd+Cu+Cr	Cu+Cr	Cu+Cr
Oct 82	PCB	PAH+PCB	PCB	PAH+PCB

Table B2
Phenanthrene Concentrations (ng/g Dry Weight) in Surficial Sediments

<u>Date</u>	<u>Station</u>				
	<u>CNTR</u>	<u>200E</u>	<u>400E</u>	<u>1000E</u>	<u>REFS</u>
8/18/82	--	--	--	--	--
11/11/82	--	--	--	--	--
12/8/82	--	--	--	--	114
12/8/82	--	--	--	--	77
3/2/83	105	101	132	--	107
3/2/83	--	--	--	--	98
3/2/83	--	--	--	--	62
6/3/83	1,560	1,960	910	52	88
6/3/83	--	--	--	63	--
7/26/83	770	1,710	240	174	51
9/1/83	780	1,010	220	168	94
9/1/83	--	--	--	--	81
3/19/84	77	98	100	250	42
3/20/84	--	--	141	78	90
3/20/84	--	--	--	--	76
3/20/84	200	--	--	--	--
9/11/84	147	57	116	109	40
10/16/84	230	--	85	137	123
10/22/85	43	440	38	69	51

Table B3

178 Alkyl Homolog Concentrations (ng/g Dry Weight) in Surficial Sediments

<u>Date</u>	<u>Station</u>				<u>REFS</u>
	<u>CNTR</u>	<u>200E</u>	<u>400E</u>	<u>1000E</u>	
8/18/82	--	--	--	--	--
11/11/82	--	--	--	--	--
12/8/82	--	--	--	--	210
12/8/82	--	--	--	--	172
3/2/83	250	210	260	--	188
3/2/83	--	--	--	--	230
3/2/83	--	--	--	--	127
6/3/83	11,000	10,000	5,300	230	189
6/3/83	--	--	--	122	--
7/26/83	9,700	13,000	1,500	412	131
9/1/83	5,200	12,000	1,480	613	186
9/1/83	--	--	--	--	189
3/19/84	1,330	590	560	600	103
3/20/84	--	--	590	260	170
3/20/84	--	--	--	--	185
3/20/84	1,200	--	--	--	--
9/11/84	3,000	270	640	250	103
10/16/84	1,260	--	240	420	240
10/22/85	490	3,800	430	210	192

Table B4

Fluoranthene Concentrations (ng/g Dry Weight) in Surficial Sediments

<u>Date</u>	<u>Station</u>				
	<u>CNTR</u>	<u>200E</u>	<u>400E</u>	<u>1000E</u>	<u>REFS</u>
8/18/82	--	--	--	--	--
11/11/82	--	--	--	--	--
12/8/82	--	--	--	--	280
12/8/82	--	--	--	--	200
3/2/83	300	260	340	--	270
3/2/83	--	--	--	--	230
3/2/83	--	--	--	--	148
6/3/83	2,300	2,300	1,240	142	220
6/3/83	--	--	--	161	--
7/26/83	1,940	2,600	570	400	140
9/1/83	1,370	2,800	560	380	220
9/1/83	--	--	--	--	210
3/19/84	290	330	330	600	124
3/20/84	--	--	360	210	230
3/20/84	--	--	--	--	185
3/20/84	510	--	--	--	--
9/11/84	650	166	410	250	108
10/16/84	580	--	240	320	300
10/22/85	172	1,770	142	196	189

Table B5

Benzo(a)pyrene Concentrations (ng/g Dry Weight) in Surficial Sediments

<u>Date</u>	<u>Station</u>				<u>REFS</u>
	<u>CNTR</u>	<u>200E</u>	<u>400E</u>	<u>1000E</u>	
8/18/82	--	--	--	--	--
11/11/82	--	--	--	--	--
12/8/82	--	--	--	--	280
12/8/82	--	--	--	--	220
3/2/83	260	270	310	--	220
3/2/83	--	--	--	--	210
3/2/83	--	--	--	--	173
6/3/83	1,640	1,490	810	122	210
6/3/83	--	--	--	158	--
7/26/83	1,520	1,750	380	370	169
9/1/83	1,000	2,100	570	320	200
9/1/83	--	--	--	--	230
3/19/84	220	350	260	450	155
3/20/84	--	--	400	280	240
3/20/84	--	--	--	--	185
3/20/84	460	--	--	--	--
9/11/84	600	230	400	260	111
10/16/84	450	--	240	320	290
10/22/85	280	1,130	230	196	380

Table B6

SUM PAH* Concentrations (ng/g Dry Weight) in Surficial Sediments

<u>Date</u>	<u>Station</u>				
	<u>CNTR</u>	<u>200E</u>	<u>400E</u>	<u>1000E</u>	<u>REFS</u>
8/18/82	--	--	--	--	--
11/11/82	--	--	--	--	--
12/8/82	--	--	--	--	5,200
12/8/82	--	--	--	--	4,500
3/2/83	5,100	4,900	5,900	--	4,400
3/2/83	--	--	--	--	4,300
3/2/83	--	--	--	--	3,300
6/3/83	62,000	59,000	30,000	2,400	3,900
6/3/83	--	--	--	3,000	--
7/26/83	54,000	63,000	10,100	7,200	3,200
9/1/83	33,000	71,000	13,500	7,200	3,600
9/1/83	--	--	--	--	4,300
3/19/84	7,200	7,100	6,200	9,300	2,700
3/20/84	--	--	7,300	4,500	3,600
3/20/84	--	--	--	--	4,300
3/20/84	11,100	--	--	--	--
9/11/84	18,600	4,400	8,600	5,000	2,000
10/16/84	11,500	--	4,800	6,700	5,800
10/22/85	5,400	34,000	4,900	3,800	5,400

* PAH = polynuclear aromatic hydrocarbons.

Table B7
Centroid Statistic in Surficial Sediments

<u>Date</u>	<u>Station</u>				<u>REFS</u>
	<u>CNTR</u>	<u>200E</u>	<u>400E</u>	<u>1000E</u>	
8/18/82	--	--	--	--	--
11/11/82	--	--	--	--	--
12/8/82	--	--	--	--	249.7
12/8/82	--	--	--	--	252.0
3/2/83	247.6	248.9	247.7	--	247.4
3/2/83	--	--	--	--	248.0
3/2/83	--	--	--	--	252.1
6/3/83	238.7	234.1	235.2	241.4	248.3
6/3/83	--	--	--	250.3	--
7/26/83	234.7	232.6	234.4	247.3	252.5
9/1/83	239.7	238.6	244.7	244.3	245.4
9/1/83	--	--	--	--	250.3
3/19/84	237.0	245.1	241.1	244.5	251.0
3/20/84	--	--	243.5	245.3	243.7
3/20/84	--	--	--	--	251.5
3/20/84	242.9	--	--	--	--
9/11/84	240.8	249.2	244.1	247.5	247.2
10/16/84	240.4	--	248.4	247.7	250.0
10/22/85	248.8	241.1	248.6	248.7	253.4

Table B8

Ethylan Concentrations (ng/g Dry Weight) in Surficial Sediments

<u>Date</u>	<u>Station</u>				<u>REFS</u>
	<u>CNTR</u>	<u>200E</u>	<u>400E</u>	<u>1000E</u>	
8/18/82	--	--	--	--	--
11/11/82	--	--	--	--	--
12/8/82	--	--	--	--	0.0
12/8/82	--	--	--	--	0.0
3/2/83	0.0	0.0	0.0	--	0.0
3/2/83	--	--	--	--	0.0
3/2/83	--	--	--	--	0.0
6/3/83	340.0	370.0	163.0	5.0	0.0
6/3/83	--	--	--	0.0	--
7/26/83	0.0	950.0	90.0	35.0	0.0
9/1/83	210.0	670.0	30.0	15.0	0.0
9/1/83	--	--	--	--	0.0
3/19/84	74.0	50.0	36.0	31.0	0.0
3/20/84	--	--	12.0	0.0	0.0
3/20/84	--	--	--	--	0.0
3/20/84	23.0	--	--	--	--
9/11/84	96.0	14.0	64.0	3.0	0.0
10/16/84	12.0	--	2.0	7.0	0.0
10/22/85	8.0	820.0	4.0	5.0	0.0

Table B9

PCB* (A1254) Concentrations (ng/g Dry Weight) in Surficial Sediments

<u>Date</u>	<u>Station</u>				<u>REFS</u>
	<u>CNTR</u>	<u>2007</u>	<u>400E</u>	<u>1000E</u>	
8/18/82	--	--	73	--	59
11/11/82	--	--	30	--	26
12/8/82	--	--	--	--	48
3/2/83	77	75	98	--	65
3/2/83	--	--	--	--	67
3/2/83	--	--	--	--	60
6/3/83	1,730	1,650	890	79	59
6/3/83	--	--	--	45	--
7/26/83	180	1,830	240	117	28
9/1/83	1,190	2,200	340	200	59
3/19/84	270	250	162	96	26
3/20/84	181	--	--	--	--
9/11/84	440	113	183	66	27
10/16/84	181	--	84	162	77
10/22/85	72	1,150	37	48	29

* PCB = polychlorinated biphenyls.

Table B10
Cadmium Concentrations (ng/g Dry Weight) in Surficial Sediments

<u>Date</u>	<u>Station</u>				
	<u>CNTR</u>	<u>200E</u>	<u>400E</u>	<u>1000E</u>	<u>REFS</u>
3/4/83	0.36	0.34	1.06	0.29	0.24
3/4/83	0.39	0.35	0.44	0.21	0.22
3/4/83	0.35	0.49	0.32	0.25	0.22
6/3/83	17.00	13.90	7.30	0.74	0.22
6/3/83	12.40	14.70	4.20	0.58	0.21
6/3/83	13.00	12.90	3.70	0.64	0.19
7/26/83	5.40	11.70	1.14	0.64	0.22
9/1/83	4.10	9.80	0.84	0.68	0.18
9/1/83	21.00	8.70	3.60	0.76	--
12/9/83	8.80	8.70	3.30	1.02	--
3/19/84	2.10	1.11	0.85	1.08	0.20
3/19/84	--	0.87	--	--	--
3/19/84	--	0.23	--	--	--
6/12/84	3.10	4.80	0.37	0.39	--
9/11/84	3.70	0.73	0.97	0.30	0.20
12/20/84	9.30	2.50	0.32	0.72	--
10/22/85	0.45	8.30	0.29	0.32	0.16

Table B11
Chromium Concentrations (ng/g Dry Weight) in Surficial Sediments

<u>Date</u>	<u>Station</u>				
	<u>CNTR</u>	<u>200E</u>	<u>400E</u>	<u>1000E</u>	<u>REFS</u>
3/4/83	56	39	59	59	48
3/4/83	53	57	43	58	52
3/4/83	45	56	56	60	54
6/3/83	870	680	340	69	49
6/3/83	780	740	191	72	48
6/3/83	800	600	155	74	48
7/26/83	120	519	69	66	44
9/1/83	310	600	106	79	56
9/1/83	680	380	160	79	--
12/9/83	520	660	117	126	--
3/19/84	100	52	54	86	47
3/19/84	--	140	--	--	--
3/19/84	--	40	--	--	--
6/12/84	138	210	41	52	--
9/11/84	153	41	128	55	44
12/20/84	550	175	47	88	--
10/22/85	54	430	57	59	40

Table B12
Copper Concentrations (ng/g Dry Weight) in Surficial Sediments

<u>Date</u>	<u>Station</u>				
	<u>CNTR</u>	<u>200E</u>	<u>400E</u>	<u>1000E</u>	<u>REFS</u>
3/4/83	67	57	67	70	55
3/4/83	62	69	63	68	57
3/4/83	63	67	64	69	58
6/3/83	1,640	1,380	680	99	48
6/3/83	1,300	1,420	360	102	51
6/3/83	1,330	1,240	303	106	56
7/26/83	450	1,230	185	106	49
9/1/83	560	1,070	134	103	47
9/1/83	1,890	910	510	122	--
12/9/83	910	950	370	177	--
3/19/84	200	111	143	123	53
3/19/84	--	107	--	--	--
3/19/84	--	114	--	--	--
6/12/84	350	530	89	83	--
9/11/84	430	86	156	73	48
12/20/84	1,000	500	52	131	--
10/22/85	92	910	75	72	46

Table B13

Iron Concentrations (ng/g Dry Weight) in Surficial Sediments

<u>Date</u>	<u>Station</u>				
	<u>CNTR</u>	<u>200E</u>	<u>400E</u>	<u>1000E</u>	<u>REFS</u>
3/4/83	21,000	17,100	22,000	23,000	19,700
3/4/83	20,000	22,000	18,900	23,000	21,000
3/4/83	18,400	21,000	21,000	23,000	22,000
6/3/83	17,100	19,200	23,000	21,000	21,000
6/3/83	19,300	19,000	22,000	21,000	19,000
6/3/83	17,900	18,700	23,000	22,000	21,000
7/26/83	15,200	16,700	21,000	16,800	21,000
9/1/83	15,100	19,300	21,000	18,400	19,700
9/1/83	26,000	15,100	--	16,400	--
12/9/83	16,500 5,800	21,000	19,600	17,500	--
3/19/84	--	17,300	20,000	18,700	21,000
3/19/84	--	16,600	--	--	--
3/19/84		15,600	--	--	--
6/12/84	6,500	17,100	19,800	15,600	--
9/11/84	12,600	17,400	18,400	18,200	21,000
12/20/84	18,100	17,300	17,400	18,000	--
10/22/85	9,900	17,200	18,100	18,900	17,000

APPENDIX C: COMPARISON OF SELECTED CONTAMINANTS IN REF AND BRH SEDIMENTS

Table C1
Concentrations of the Ten Selected Contaminants and Two Summary Statistics
for Both BRH and REF Sediments. Means \pm Standard Deviations

Chemical Compound	Sediment*	
	BRH	REF
Phenanthrene	5,000 \pm 1,800 (15)**	85 \pm 17 (12)
Sum of 178 alkyl homologs	28,000 \pm 8,300 (15)	170 \pm 26 (12)
Fluoranthene	6,300 \pm 1,300 (15)	240 \pm 33 (12)
Benzo(a)pyrene	3,900 \pm 970 (15)	250 \pm 28 (12)
Ethylan	4,000 \pm 820 (15)	0 \pm + (12)
PCB as A1254	6,400 \pm 840 (15)	39 \pm 4 (12)
SUM of PAHs	142,000 \pm 30,000 (15)	4,500 \pm 510 (12)
Centroid of PAHs	232.8 \pm 1.7 (15)	249.2 \pm 1.7 (12)
Copper	2,900 \pm 310 (18)	60 \pm 3 (15)
Cadmium	24 \pm 0.6 (18)	0.23 \pm 0.04 (15)
Chromium	1,480 \pm 83 (18)	50 \pm 15 (15)
Iron	31,000 \pm 2,800 (18)	21,000 \pm 1,400 (15)

* Units are nanograms per gram dry weight for the organic compounds and the statistic SUM, micrograms per gram dry weight for the inorganic elements, and molecular weight for the statistic centroid.

** (N) = number of sediment samples analyzed.

END

FILMED

FEB. 1988

DTIC